FINAL REPORT

GOLD/SILVER HEAP LEACHING AND MANAGEMENT PRACTICES THAT MINIMIZE THE POTENTIAL FOR CYANIDE RELEASES

by

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NOTICE

FOREWARD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of the State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report presents a description of the magnitude and distribution of gold/silver heap leaching, the design and operation of leaching facilities, the potential for environmental impact, and management practices that can be used to minimize environmental releases. The objectives of this study were to describe the design and operation of current gold and silver heap leaching operations, to summarize briefly the issues of toxicity and mobility of cyanide in the environment as related to heap leaching, to develop conceptual alternative management practices for both existing and new facilities, and to develop cost estimates for these conceptual controls and practices.

The data included in this report were obtained primarily from a literature search and from visits to several major heap leaching operations in Nevada. The intent of the literature search was to collect information on heap leaching practices, recovery technologies, and the environmental impact of cyanide leaching operations in the gold and silver mining industry segments. State environmental personnel and experts from organizations such as the Bureau of Mines were consulted to identify available information dealing with heap leach practices and control technologies. Six active heap leach operations were visited to obtain information on industry practices and the characteristics of the leaching process.

Thomas Hauser, Director
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ABSTRACT

This report presents a description of the magnitude and distribution of gold/silver heap leaching, the design and operation of leaching facilities, the potential for environmental impact, and management practices that may be used to minimize potential environmental releases. The information contained in the report was obtained through searches of published and unpublished literature and through contact with knowledgeable individuals involved in the heap leaching industry. Several leaching operations were visited to acquire firsthand knowledge and site-specific information.

Currently, there are about 78 active heap leach operations in the United States. The majority of these sites are located in Nevada. Heap leaching is percolation leaching of low-grade gold and silver ores that have been stacked in engineered heaps on specially constructed pads. An alkaline cyanide solution is the only lixiviant used. Relatively impervious pads (e.g., 10^{-7} cm/s) constructed of synthetic or clay materials and lined (HDPE, PVC, etc.) ponds and trenches are used at all sites.

There are very few data available on the concentration of cyanide remaining in heap leach residue after operations cease. No damage cases were identified that indicated impact from properly constructed or operated facilities.

Several management practices (i.e., french drains, double pond liners, alternative lixiviants, cyanide destruction, ground-water monitoring, and capping) were assessed. Costs of each of these systems were estimated for an example facility.

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(continued)

FIGURES

(continued)

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SECTION 1

INTRODUCTION

BACKGROUND

Since the surge in precious metal prices in the 1970's, gold has continued to be the bright spot in the domestic metal mining industry.[1] This trend is expected to continue, and reserves are likely to be enlarged as the result of increased exploration activity.[1] Because of the low capital investment and fast payout involved, the production of gold by heap leaching is becoming increasingly popular.[1,2] This method permits operators to process small quantities of low-grade newly mined ores, waste rock, and tailings from previous mining activities. Currently, the United States has about 78 active heap leach operations, about 50 of which are located in Nevada. The others are scattered throughout California, New Mexico, Colorado, South Dakota, Idaho, and Montana. Only two operations, both in South Carolina, are located in the eastern United States.

Cyanide is the only commercially proven lixiviant available for the heap leaching of low-grade gold and silver ores, and the U.S. Environmental Protection Agency (EPA) is concerned about whether adequate measures are being taken to ensure protection of the environment. In the EPA's Report to Congress on mining wastes, the Agency indicated its intent to conduct additional studies on mining wastes containing cyanide.[3] In the recent regulatory determination regarding mining wastes and RCRA, the Agency indicated that it will "...focus on identifying environmental problems and setting priorities for applying controls at mining sites with such potential problems as high acid-generation potential, radioactivity, asbestos and cyanide wastes."[4] This report represents one of the EPA's efforts to supplement the data base on the issue of cyanide and mine waste. A brief discussion of the mining waste issue is presented in the following paragraphs so that the current study may be placed in context.

In 1976, Section 8002(f) of the Resource Conservation and Recovery Act (RCRA) required the EPA to conduct an investigation of all solid waste management practices in the mining industry. That mandate specifically directed EPA to conduct "...a detailed and comprehensive study on the adverse effects of solid wastes from active and abandoned surface and underground mines on the environment, including, but not limited to, the effect of such wastes on humans, water, air, health, welfare, and natural resources."[5]

When Congress amended RCRA in 1980, it added Section 8002(p), which directed EPA to conduct a "...detailed and comprehensive study on the adverse effects on human health and the environment, if any, of the disposal and utilization of solid wastes from the extraction, beneficiation, and processing of ores and minerals."[6] Moreover, it required EPA to make a "regulatory determination" within 6 months after submitting the study to Congress, stating either that regulations would be promulgated or that regulations were unwarranted for such mining wastes. A report, mandated by Sections 8002(f) and (p), was submitted to Congress on December 31, 1985.[3]

On July 3, 1986, the EPA published the regulatory determination regarding the issue of mining wastes that heretofore had been excluded from regulation under RCRA.[4] The determination indicated that RCRA's hazardous waste management standards "...are likely to be environmentally unnecessary, technically infeasible, or economically impractical when applied to mining wastes." The EPA indicated that it plans to develop a special program for mining wastes under Subtitle D, but acknowledged that, after additional study, some mining wastes may have to be regulated under Subtitle C. The EPA specifically expressed continued concern about problems and potential problems associated with mining wastes having high-acid generation potential, radioactivity, asbestos, and cyanide. The EPA's current policy, as stated in the regulatory determination, regarding active heap leach piles and leach solutions is that these materials are not wastes, but rather are raw materials used in the production process and a product, respectively.[4] Only leach solutions that escape from the production process and abandoned heap leach piles are wastes.

To develop a mining waste program under Subtitle D, EPA is collecting additional information on the nature of mining wastes, mining waste management practices, and mining waste exposure potential. Toward this end, EPA's Office of Research and Development contracted PEI Associates, Inc. to conduct an evaluation of the gold and silver heap leaching (cyanide leaching) industry. This report characterizes the industry, describes current design and operational practices, summarizes environmental concerns, and presents conceptual alternative management practices that could mitigate potential impacts which may be caused by cyanide contamination from this industry segment. Several heap leach operations were visited to obtain information on current industry and site-specific practices. Practices that could mitigate actual or potential escape of cyanide were identified and evaluated.

PURPOSE AND SCOPE

The objectives of this study were to describe the design and operation of current gold and silver heap leaching operations, to summarize briefly the issues of toxicity and mobility of cyanide in the environment as related to heap leaching, to develop conceptual alternative management practices for both existing and new facilities, and to develop cost estimates for these conceptual controls and practices.

The data included in this report were obtained primarily from a literature search and from visits to several major heap leaching operations in Nevada. The intent of the literature search was to collect information on heap leaching practices, recovery technologies, and the environmental impact of cyanide leaching operations in the gold and silver mining industry segments. State environmental personnel and experts from organizations such as the Bureau of Mines were consulted to identify available information dealing with heap leach practices and control technologies. Six active heap leach operations were visited to obtain information on industry practices and the characteristics of the leaching process.

REPORT ORGANIZATION

Section 2 of this project report contains an overview of the heap leaching industry and provides the current status of the industry and the geographic distribution of active sites. Section 3 discusses the design and operation of current heap leaching operations. Section 4 presents a summary of the toxicity and mobility of cyanide as it is related to heap leaching. Section 5 discusses conceptual alternative management practices that could limit or prohibit actual and potential releases of cyanide from heap leaching and their application. Cost estimates of example applications are also presented. Section 6 summarizes the information and presents comments on the likely effectiveness and applicability of conceptual alternative management practices and control techniques. Trip reports covering the six visits are included as Appendix A.

SECTION 2

OVERVIEW OF THE HEAP LEACHING INDUSTRY

OVERVIEW OF HEAP LEACHING

Heap leaching--percolation leaching with cyanide of relatively coarse, low-grade gold/silver ore piled on an impervious surface--was first suggested by the Bureau of Mines in 1969.[7] This processing method is suitable for processing ores containing free, disseminated, submicron particles of gold and/or silver in porous host rock.[7] Increases in the price of gold during the 1970's, stimulated by removal of restraints on private ownership, resulted in efforts to improve the process and make it more widely applicable. In the mid-1970's, the Bureau of Mines developed the process of agglomeration, which permits the leaching of low-grade clayey deposits. Since the early 1970's, heap leaching facilities have been developed that range in size from small, one-man intermittent and batch operations to large, well-capitalized operations capable of the continuous processing of up to 20,000 tons of ore per day. In 1984, about 525,000 troy ounces of gold was recovered from 20,000,000 tons of ore treated by cyanide heap leaching.[8] By comparison, 1,140,000 troy ounces of gold was recovered from conventional cyanidation extraction in vats, tanks, and closed containers.[8] The average ore grade treated by heap leaching operations is about 0.05 ounce of gold/ton and 0.09 ounce of gold/per ton of ore by conventional cyanidation. As shown in Table 1, the application of cyanide heap leaching has grown over recent years, and this trend is expected to continue.

The relatively small capital investment and low operating costs of heap leaching have made it an increasingly attractive method for recovery of gold and silver from low-grade resources. The capital costs of heap leaching are 20 to 36 percent of those required for conventional cyanidation milling.[9]

TABLE 1. GOLD PRODUCED IN THE UNITED STATES BY CYANIDATION[a,b]

Year	Extraction in vats, tanks, and closed containers[c]		Leaching in open heaps or dumps[d]	
	Ore treated, short tons	Gold recovered,[e] troy ounces	Ore treated, short tons	Gold recovered, troy ounces
1980	7,869,000	483,000	3,910,000	120,000
1981	7,024,000	648,000	8,875,000	264,000
1982	7,616,000	711,000	12,290,000	391,000
1983	11,317,000	1,086,000	16,180,000	499,000
1984	12,064,000	1,136,000	19,860,000	525,000

[a] Source: Reference 8.

[b] May include small quantities recovered by leaching with thiourea, by bio-extraction, and by proprietary processes.

[c] Includes autoclaves.

[d] May include tailings and waste ore dumps.

[e] May include small quantities recovered by gravity methods.

Operating costs are 40 to 55 percent of those for the conventional cyanidation process.[9] Average production costs are about $290/oz., and many operations are below $200/oz. Heap leaching facilities also entail a shorter startup period and can be applied on a small scale. The efficiency of heap leaching, however, is less than that of conventional cyanidation which uses an agitated leach. The conventional process achieves about 90 percent recovery, while heap leaching recoveries range from 50 to 85 percent.[9] Heap leach operations that process newly mined run-of-mine ore usually recover about 50 to 60 percent of the metal values, whereas operations that process ores subjected to crushing and agglomeration may recover 75 to 85 percent.[9]

The basic heap leaching process involves spraying an alkaline cyanide solution (pH 9 to 11) over ore that has been stacked on a sloped, impermeable pad. Metal values (gold and silver) are dissolved in the solution and flow off the pad to a lined impoundment. This pregnant solution is pumped from the impoundment to a metals-recovery process, where the gold and/or silver are removed. The barren solution with makeup reagents (i.e., sodium cyanide and lime) is returned to the ore to complete a closed loop. This process is depicted conceptually in Figure 1. After the leaching is completed, the leach residue is rinsed with fresh water, drained, and either left on the pad

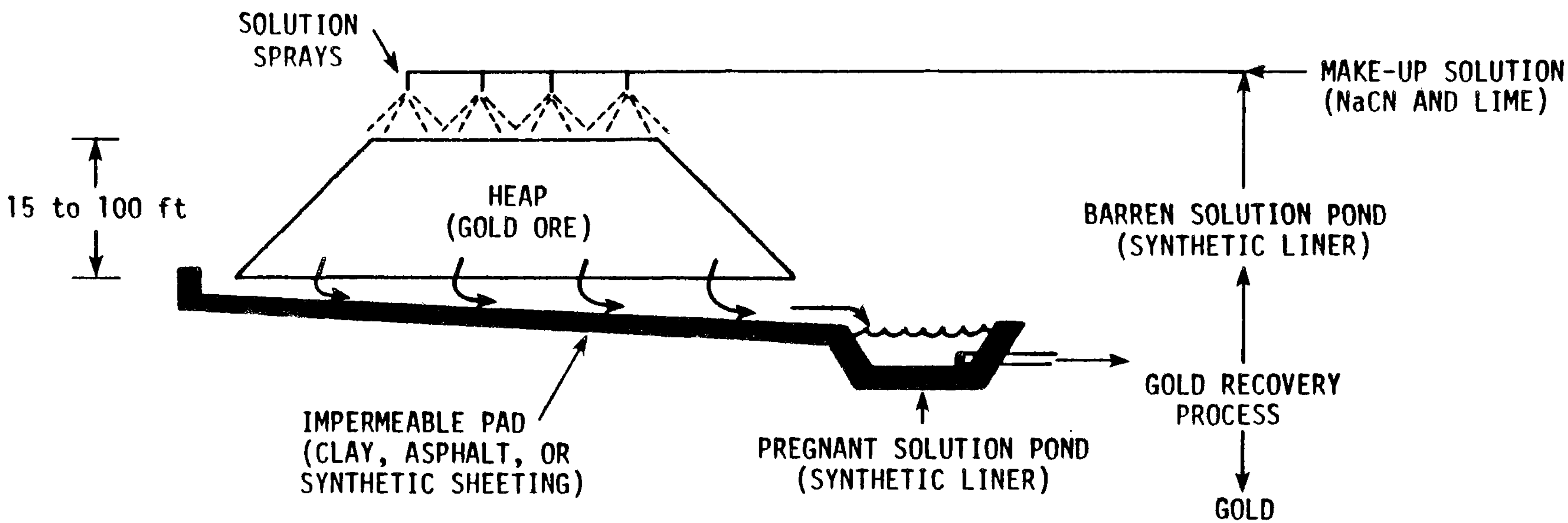


Figure 1. Conceptual flow diagram of a heap leach operation.

or excavated and hauled to a disposal area on site. Although the basic process is constant, site-specific factors dictate specific design and operational parameters. The design and operation of heap leach facilities are discussed in Section 4, and examples are presented.

Cyanide is the only commercially proven lixiviant used in heap leaching. The basic principle involved is that a weak alkaline cyanide solution preferentially dissolves gold and silver contained in the ore.[7] The cyanidation reaction proceeds in two stages.[7] Most of the gold is dissolved by the following reaction:

$$2\ Au + 4\ CN^- + O_2 + 2\ H_2O \rightarrow 2\ Au(CN)_2^- + H_2O_2 + 2\ OH^- \qquad \text{(Eq. 1)}$$

A small but significant portion of the gold is dissolved by the reaction shown in Equation 2-2.

$$4\ Au + 8\ CN^- + O_2 + 2\ H_2O \rightarrow 4\ Au(CN)_2^- + 4\ OH^- \qquad \text{(Eq. 2)}$$

The rate of the cyanidation reaction depends on the concentration of cyanide and the alkalinity of the solution; a pH between 10 and 11 is usually optimum.

Sodium cyanide (NaCN) is used as the source of cyanide by all heap leach operations. It typically is purchased in bulk solid form. Sodium cyanide is available in nonreturnable 100-lb-net and 200-lb-net steel drums and 1-ton boxes and in returnable 3000-lb-net FLO-BIN[R] containers. Used sodium cyanide drums must be triple rinsed and disposed of appropriately. When returnable bins are used, the customer does not have to clean or dispose of containers. Lime (CaO) or caustic soda (NaOH) is used to maintain the alkalinity of the leach solution in a pH range of 9 to 11.[7] Reagent usage differs from site to site and depends on ore characteristics. If cyanicides (materials that destroy cyanide or otherwise inhibit the cyanidation reaction) are present in the ore, relatively greater quantities of cyanide have to be added to the leaching solution. Cyanicides include arsenic-bearing minerals such as realgar (As_2S_2) and orpiment (As_2S_3), and others, such as stibnite (Sb_2S_3), that react rapidly with cyanide and inhibit dissolution of gold; carbonaceous materials that act as adsorbents for dissolved gold; base metal ions, such as Fe^{2+}, Fe^{3+}, Ni^{2+}, Cu^{2+}, Zn^{2+}, and Mn^{2+}, which retard cyanidation; acids that hydrolyze cyanide; and organics that consume the dissolved oxygen necessary for the reaction.[7] The quantity of caustic, lime, or caustic soda required is also determined by ore mineralogy. If acid-forming constituents are present, more caustic will be required to maintain the high-pH protective alkalinity necessary for the cyanidation reaction.

Precious metal recovery usually is accomplished by either carbon adsorption followed by eluting and electrowinning or by Merrill-Crowe zinc dust precipitation.[10] Typically, the dissolved gold and silver are recovered from the pregnant solution on site; however, small operations may ship loaded carbon off site for metal recovery. Other possible metal recovery systems include ion exchange, direct electrowinning, soluble sulfide precipitation, and aluminum dust precipitation.[10]

INDUSTRY STATUS

The mining industry first became interested in the U.S. Bureau of Mines' developments in gold/silver heap leaching technology in the late 1960's, and the first commercial cyanide heap leaching process was used at the Carlin Gold Mine Company in northern Nevada on mine cutoff material. Since the early 1970's, interest in heap leaching has continued to grow primarily in response to the high prices of gold and silver. Low-grade (e.g., 0.03 oz/ton) gold deposits previously considered uneconomical to recover are now being exploited at a profit.[10]

A 1984 survey indicated that more than 80 operations were experimenting with leaching, actively leaching, or seriously planning to use heap leaching.[2] At the time of the survey, 48 facilities were reportedly actively heap and dump leaching precious metals in Arizona, California, Colorado, Montana, and Nevada. Twenty-one facilities were planning leaching operations, seven facilities were inactive, and the status of leaching operations at the remaining sites was unknown. Reportedly, the great number of permits being issued made it impossible to compile a complete up-to-date list of heap leaching operations.[2] For comparison, a 1981 survey reported 38 active gold and silver heap and dump leaching operations." This represents an increase of about 21 percent over a 3-year period. As indicated by the survey data, gold and silver heap leaching operations were experiencing a dramatic increase in popularity.

During this project, an effort was made to compile an updated listing of active gold and silver heap leaching operations. Several sources were used to generate this listing. First, a literature search was conducted of several popular mining journals (i.e., Engineering and Mining Journal, Mining Congress Journal, and Mining Engineering) from 1981 to the present. Articles discussing heap leaching operations were extracted to track operational developments at individual facilities. The 1984 and 1985 issues of Heap and Dump Leaching International Newsletter (published quarterly by DHL Company in Lakewood, Colorado) were also reviewed. The 1985 and 1986 issues of Mineral Industry Surveys (prepared monthly and quarterly by the U.S. Bureau of Mines) also were reviewed for recent developments and to determine the operational status of heap leach facilities. A document entitled "Directory of Nevada Mine Operations Active During Calendar Year 1985" (compiled by the Department of Industrial Relations, Division of Mine Inspection in Carson City, Nevada) and a 1985 (fourth quarter) Mine Safety and Health Administration directory of metal mines were obtained from the State of Nevada. These directories were very helpful in the development of a listing of active heap leaching operations.

In addition to published sources of heap leaching operational information, PEI contacted the U.S. Bureau of Mines offices and State agencies listed in Table 2 to obtain the most current operational status information and to refine the listing of active heap leaching facilities generated from the literature search.

Currently, about 78 gold and silver heap leaching operations are active in the United States. The majority (47) of these operations are in Nevada. Ten of the active heap leaching operations are in California, nine in Colorado, two in Idaho, three in Montana, one in New Mexico, two in South Carolina, three in Utah, and one in South Dakota. Alligator Ridge and Zortman-Landusky are the largest producers of gold from heap leaching; each facility generates approximately 70,000 troy ounces per year. Other large gold producers are Smoky Valley (60,000 oz/yr) and Northumberland (40,000 oz/yr). The largest U.S. producer of heap leach silver is NERCO Mineral's Candelaria Mine, which currently produces more than 2 million ounces of silver annually. The next largest silver producer is Zortman-Landusky, which produces 125,000 ounces per year as a valuable coproduct. A listing of active heap leach operations by state is presented in Table 3. The maps shown in Figures 2 and 3 indicate the approximate locations of these heap leaching operations.

TABLE 2. AGENCIES CONTACTED FOR LISTING OF ACTIVE HEAP LEACH FACILITIES

State	Agency	Contact
Arizona, Colorado, New Mexico	U.S. Bureau of Mines Intermountain Field Operations Center Denver, Colorado	Dan Witkowsky (303) 236-0421
California, Nevada	U.S. Bureau of Mines Reno Research Center Reno, Nevada	Fred Carillo (702) 784-5215
Idaho, Montana	U.S. Bureau of Mines Western Field Operations Center Spokane, Washington	Bill Rice (509) 456-5350
Arizona	State of Arizona Department of Mines & Minerals Resources Phoenix, Arizona	Ken Phillips (602) 255-3791
California	State of California Department of Conservation State Water Resources Control Board Sacramento, California	Charlene Herbst (916) 445-3993
Colorado	State of Colorado Division of Mines Denver, Colorado	Floyd Dooley (303) 866-3567
Nevada	State of Nevada Department of Conservation and Natural Resources	Harry Van Drielen (702) 885-4670
	Department of Industrial Relations Division of Mine Inspection	Norton Pickett (702) 885-5243
New Mexico	State of New Mexico Bureau of Mines and Mineral Resources Socorro, New Mexico	Mike Harris (505) 835-5420
South Carolina	State of South Carolina Land Resources Conservation Commission	Craig Kennedy (803) 734-9100
Utah	State of Utah Department of Natural Resources Division of Oil, Gas, and Mining Salt Lake City, Utah	David Wham (801) 538-5340

TABLE 3. ACTIVE PRECIOUS METAL HEAP LEACH OPERATIONS IN THE UNITED STATES[a]

State/company	Operation	Product metal	
		Gold	Silver
California			
Glamis Gold, Ltd.	Picacho	x	
Carson Hill Mining Co.	Carson Hill	x	
Gold Fields Mining Corp.	Mesquite	x	
Royal Gold, Inc.	Calgom	x	
Rand Mining (formerly Chemgold)	Randsburg	x	
Catus Gold Mines Co.	Catus Gold	x	
Shell Mining	Standard Hill	x	
Rattle Snake Mining Co.	Rattle Snake Mine	x	
Castle Mt. Mining	Castle Mt.	x	
American Girl Gold Mining Corp.	American Girl	x	
Colorado			
Cripple Creek and Victor Gold Mining Co.	Carlton Operation	x	x
	Victory Operation	x	
Saratoga Mines, Inc.	Saratoga	x	
Galactic Resources	Summitville	x	x
H&M Joint Venture	Doves Nest	x	
Great West	Vulcan Project	x	
Crystal Hill Mining	Crystal Hill	x	
Little Pedro Mining	Jerry Johnson Group	x	
Hull Mining Co.	Rubie Operation	x	
Idaho			
Pioneer Metals Corp.	Stibnite Mine	x	
Coeur d'Alene Mines Corp.	Thunder Mountain Mine	x	
Montana			
Zortman Mining Inc. - Pegasus Explorations, Ltd.	Ruby Gulch	x	x
Landusky Mining Inc. - Pegasus Explorations, Ltd.	August Mine, Gold Bug Mine	x	x
Mt. Hagen Mining Co.	Crenshaw Mine	x	
Nevada[b]			
Millcreek Mining, Inc.	Fondaway Canyon Mine		x
Windfall Venture	Windfall Mine	x	
Newmont Gold Co. (formerly Carlin Gold Co.)	Bootstrap Plant	x	
	Gold Quarry Mine	x	
	Maggie Creek Plant	x	
Cominco American, Inc.	Buckhorn Mine	x	x
Pinson Mining Co.	Pinson Mine & Mill	x	
	Preble Mine	x	
Cortez Gold Mines	Cortez Gold Mine & Mill	x	

(continued)

TABLE 3 (continued)

State/company	Operation	Product metal	
		Gold	Silver
Nevada (continued)			
NERCO Metals, Inc.	Candelaria Mine	x	x
CanAm	Borealis Mine	x	x
Smoky Valley Mining Co.	Round Mountain Gold	x	
Cyprus Mines Corporation	Northumberland Mine & Heap	x	x
Lacana Gold, Inc. (Pegasus)	Relief Canyon Mine	x	x
Amselco Minerals, Inc.	Alligator Ridge Gold Mine	x	
Hi-Tech Corp.	Hi-Tech Mill	x	x
Kenneth C. Jones	Desert Rat Mine	x	x
Belmont Resources (U.S.), Inc.	Wonder Mine	x	x
Joe Williams	Oasis Mine & Mill	x	x
Tonkin Springs Gold Mining Co.	Tonkin Springs Project	x	
Panhandle Drilling & Blasting, Inc.	Tonkin Springs Project	x	
Western Arlington Resources, Inc.	Wall Street Mine	x	x
Tomi-Gee Mining Co., Inc.	Tomi-Gee Mine & Mill	x	
Dee Gold Mining Co.	Dee Gold Mine	x	
Priet Joint Venture	Cornucopia Mine	x	x
Birco Development & Joe Stock	Bluster Mill Site	x	x
Blackhawk Mines Corp.	Goldfield Tailings Project	x	x
H,C&C Mining, Inc.	H,C&C Mining Mill	x	
Falcon Mining & Exploration Co.	Falcon Exploration Mine & Mill	x	x
Vector Exploration, Inc.	Goldfield Project	x	x
Western States Minerals Corp.	Gold Strike Mine & Mill	x	
E.B. King	Jumbo Mine	x	
Silver Coin Mining Co.	Silver Coin Mine		x
The Standard Slag Co.	Lewis Mine	x	x
S.W. Mining	Gold Bug Claims 1 through 8	x	x
FRM Minerals, Inc.	Getchell Project	x	
Bauer Metals, Inc.	Bauer Metals Millsite	x	x
Alhambra Mines, Inc.	Dayton Tailings	x	x
Alhambra Mines, Inc.	Dayton Tailings	x	x
N-M Recovery Corp.	Stanmore Mine	x	x
Centennial Minerals, Inc.	Aurora Trial Heap Leach	x	x
Saga Exploration Co.	Sterling Mine	x	x
Ivy Minerals	Old Sullivan Mine	x	
Minerals Associates, Inc.	Rose-Dale Mine	x	
Placer Amex, Inc.	Bald Mountain Project	x	
Nevex Gold Co., Inc.	Santiago-Haywood Mine	x	x
New Dynasty Mines (U.S.), Inc.	Little Bald Mountain	x	
New Mexico			
Westar Corp.	Lordsburg	x	

(continued)

TABLE 3 (continued)

State/company	Operation	Product metal	
		Gold	Silver
South Carolina			
Peidmont Mining Co.	Haile Gold Mine	x	
Westmont Mining Co.	Brewer Gold Mine	x	
South Dakota			
Wharf Resources	Annie Creek	x	
Utah			
Mercur Hill Gold Property	Barrick Mercur Gold Mines	x	
Timberline Industries, Inc.	Ophir Canyon		
Vipont Mines, Ltd.	Vipont Mine	x	x

[a] Based on data obtained by PEI Associates, Inc., during telephone communications with Bureau of Mines State Activity Officers and State regulatory officials.

[b] Directory of Nevada Mine Operations Active During Calendar Year 1985. Department of Industrial Relations, Division of Mine Inspection. State of Nevada. September 1986.

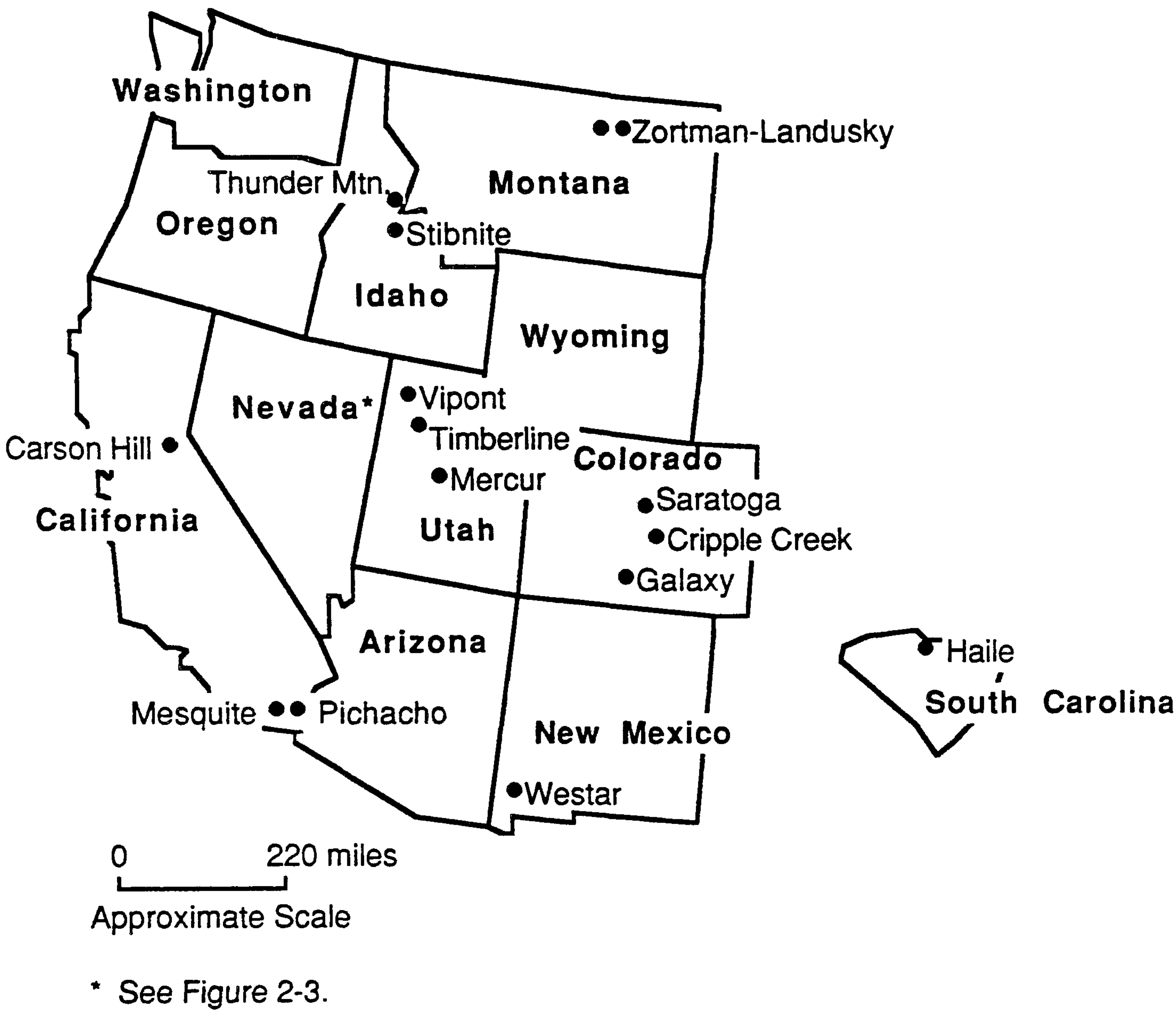


Figure 2. Approximate location of several gold/silver heap leach operations.

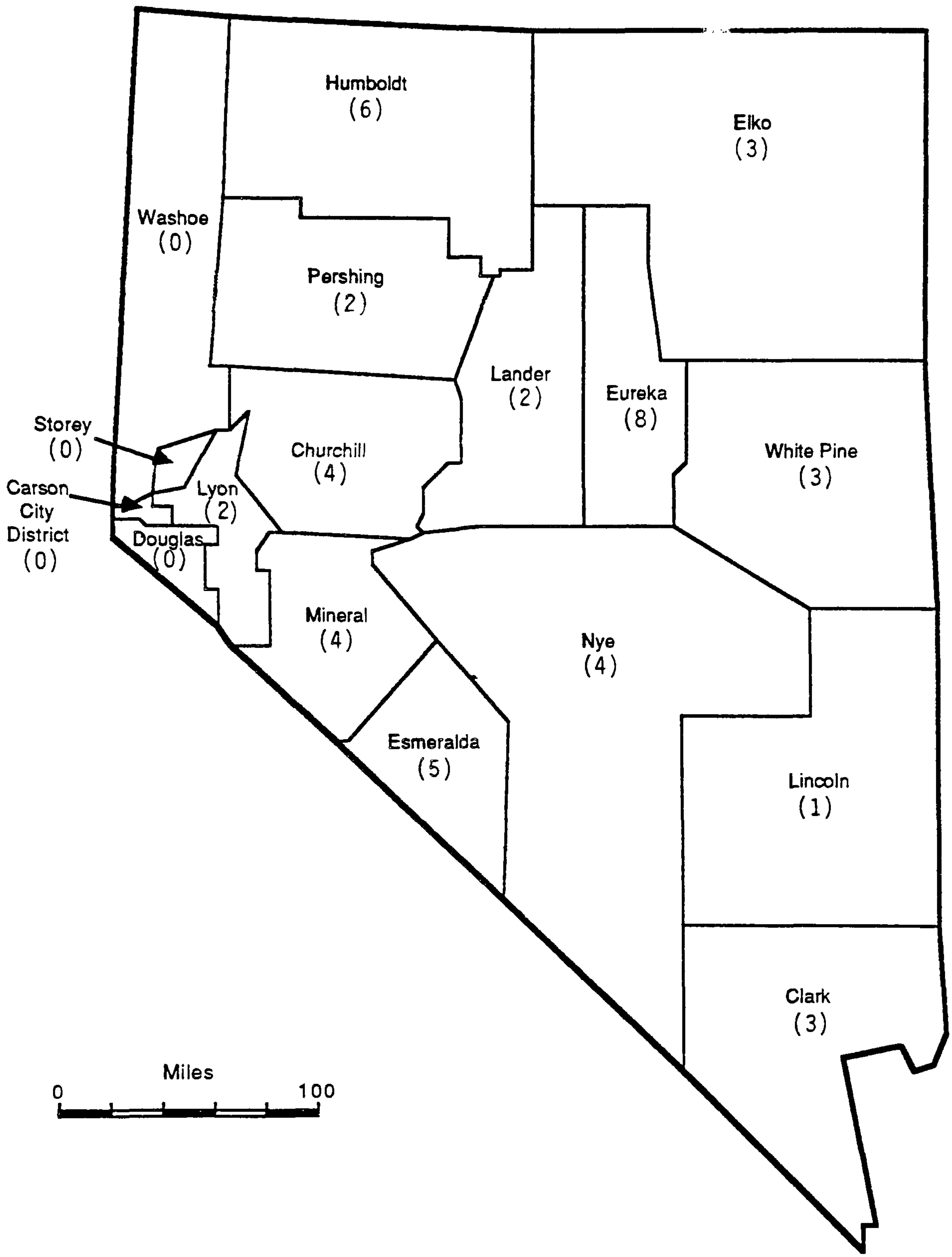


Figure 3. Number of gold/silver heap leach operations by county in Nevada.

(Based on Directory of Nevada Mine Operations Active During Calendar Year 1985. Department of Industrial Relations, Division of Mine Inspection. State of Nevada, September 1986)

SECTION 3

DESIGN AND OPERATION OF HEAP LEACHING PROJECTS

INTRODUCTION

The basic design and operational layout of heap leach projects are very similar at all facilities. Low-grade ore is stacked in engineered heaps on sloped, impermeable pads and a weak alkaline cyanide solution is sprayed over the ore. The solution percolates through the heap and dissolves the metal values (gold and/or silver). This pregnant solution then flows over the pad to a lined collection ditch. The ditch carries this gold-bearing cyanide solution to a lined pregnant solution pond. The pregnant solution is then pumped to a recovery plant, where the metal product is removed by carbon adsorption followed by stripping and electrowinning or by precipitation with zinc followed by filtration (Merrill-Crowe zinc dust precipitation). The barren solution is then pumped to a lined holding pond, where it is treated with additional NaCN and caustic (e.g., lime or caustic soda). From the barren pond, the solution is again pumped to the heap and sprayed over it to complete the closed-loop cycle. Heap leach operations are typically zero discharge facilities.

A conceptual flow diagram of the heap leach operation is presented in Figure 4. Although the basic process just described is similar at all operations, each site is unique, and several alternative approaches exist. Specific leaching times, cyanide concentrations, reagent use, flow rates, heap dimensions, pad construction, pond capacities, liner materials, and other design and operational parameters vary from site to site, depending on the characteristics and quantity of the ore and the climate, topography, hydrology, and hydrogeology of the site.

MINING AND ORE PREPARATION

Low-grade gold ores (i.e., 0.03 to 0.05 oz/ton) and low-grade silver ores (i.e., 1 to 4 oz/ton) with finely disseminated free metal particles are

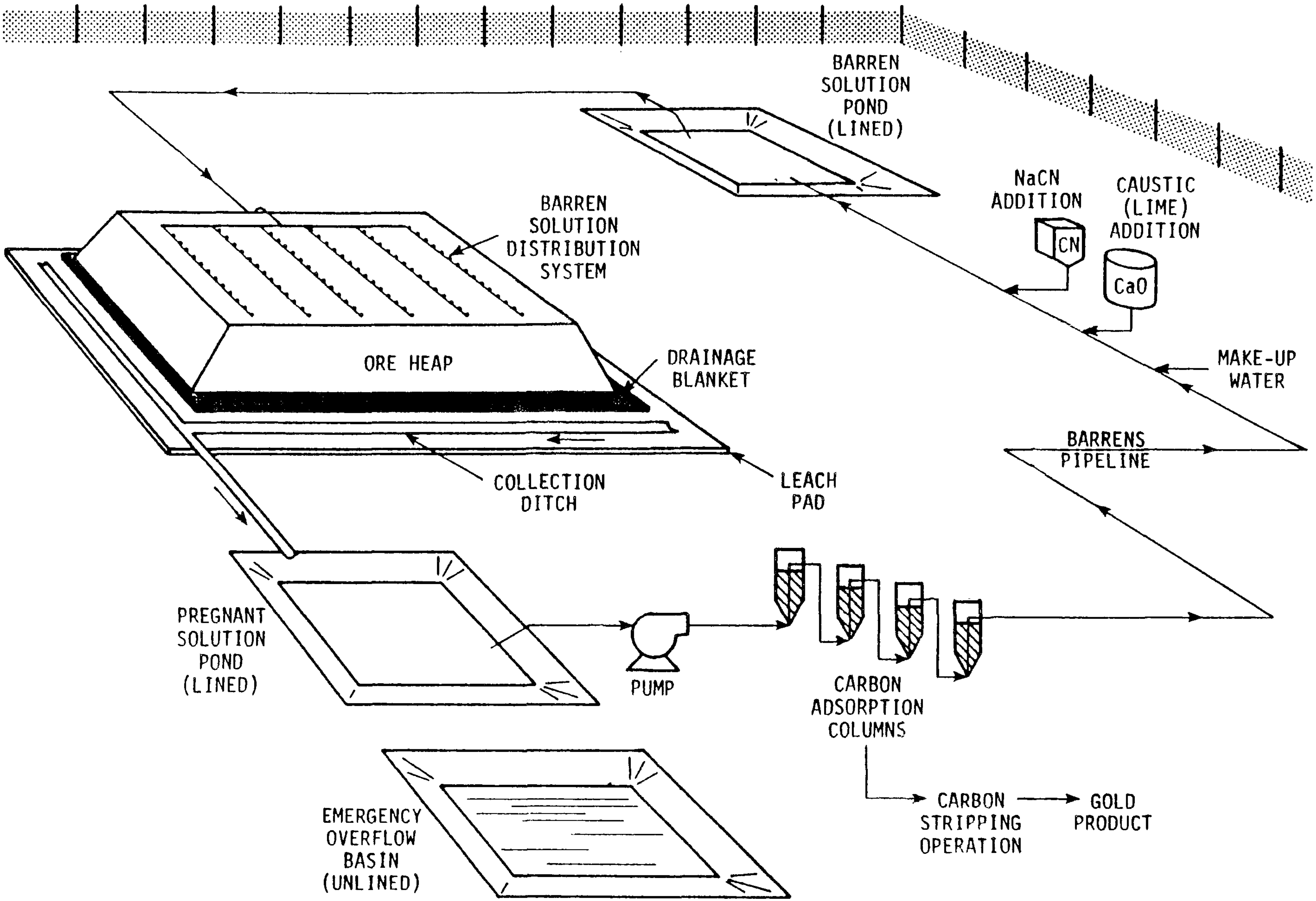


Figure 4. Conceptual flow diagram of typical heap leach operation.

amenable to heap leaching. Heap leaching is applied not only to newly mined low-grade ore, but also to waste rock dumps and tailings from previous operations. Some ores (i.e., refractory ores) do not respond to cyanidation. Refractory ores include carbonaceous ores (carbon prevents much of the gold from dissolving and adsorbs any dissolved metal before recovery), pyritic ores, and complex sulfide ores. Also, copper, cobalt, and zinc in the ore may preferentially take the place of gold and silver in the leaching reaction and reduce the extraction efficiency.[2] If the metal values are totally encased by an impervious matrix (e.g., quartz), leach solutions cannot contact the gold. The following major ore types are amenable to heap leaching: oxidized, disseminated, sulfide ores in which precious metals are not intimately associated with sulfide minerals, and certain load or placer deposits that contain fine particles of gold.[12] Most of the ores subjected to heap leaching are obtained from surface mines.

Newly mined ore is either placed on the leach pad without crushing and leached as run-of-mine ore, or subjected to crushing or crushing and agglomeration prior to leaching. The treatment of the ore is a function of site economics (i.e., tradeoffs between increased recovery and cost of treatment) and ore mineralogy and it is determined through bench- and pilot-scale tests during the development stage of the operation.

The heap must be built with ore that is uniformly permeable so the leach solution contacts the available metal values contained therein. The ore must also be physically strong enough to be placed in heaps and to maintain its structural stability when wetted. Many resources that previously (pre-1980) could not be heap-leached because of poor permeability or lack of structural strength due to the presence of clays or fine particles in the ore can now be leached after agglomeration. The Bureau of Mines suggested this process in 1979, and it has become a relatively common treatment practice, especially necessary when old tailings are being leached.[13] Agglomeration involves the following sequence of operations: crushing ore particles to a minus 1-inch or finer size, treating the ore with 5 to 10 pounds of portland cement per ton of ore, wetting it with water or a strong cyanide solution to achieve 8 to 16 percent moisture, mechanically tumbling it, and curing it.[14] Agglomeration causes the clay and fine particles to adhere to coarser particles present in the ore and this prevents these fines from segregating in the heap and causing binding (impermeable zones) and solution channeling. In addition, if cyanide is used during agglomeration, the leaching process is initiated before the ore is stacked on the pad and may reduce leach cycle time and increase metal recovery. Agglomeration effectively promotes good percolation characteristics in low-grade resources, particularly tailings, that otherwise could not be heap-leached. The cement added during agglomeration also aids in maintaining the alkaline pH necessary for cyanide leaching (optimum pH is 10.3).

Crushing and agglomeration involve a significant capital outlay for equipment and materials or represent a significant operating cost if done on a contract basis. For comparison purposes, $2 to $3 per ton of ore represents the typical mining costs for heap leach operations, whereas crushing and agglomeration can cost from $1.85 to $4.35 per ton in addition to the mining costs.[15] At a large operation the expenditure for the equipment and materials necessary for agglomeration could well be several million dollars.[15]

In summary, mining and ore preparation entails two major considerations: 1) that material to be heap-leached contains gold and/or silver amenable to cyanidation, and, 2) that the material allows a high rate of percolation throughout the heap. Crushing can expose more precious metal to the lixiviant, but it adds to the cost. Increases in recoveries after crushing must be sufficient to offset the added cost. Agglomeration can be used to make some materials amenable to heap leaching that otherwise could not be treated in this manner.

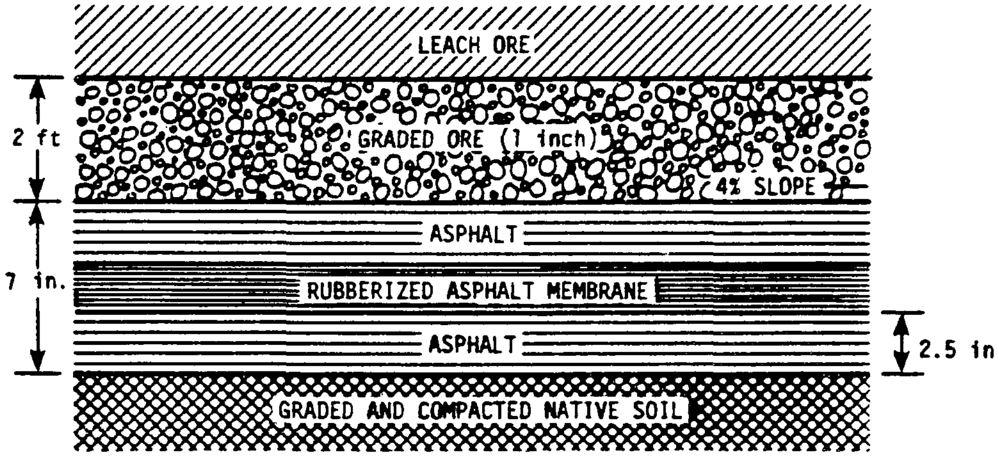
PAD CONSTRUCTION

An impermeable pad must be constructed to ensure that product and reagents are not lost through seepage from the heap. In this case, the goals of the operator and environmentalist are the same. Leach pads normally are constructed on smooth, gently sloping ground (1 to 6 percent slopes); however, heaps can be constructed in areas of high relief by using a technique called "valley fill." (This modified version of a heap leach operation is discussed later in this section.) The leach pad is sloped so that pregnant solution is directed to a lined collection ditch situated along the one or two downgrade sides of the pad. Pads are constructed of native clays, modified clays, asphalt, or synthetic materials such as HDPE (High Density Polyethylene), PVC, or Hypalon. The pads not only must be relatively impermeable (i.e., 10^{-7} cm/s), they also must be capable of providing structural support for the heap without suffering damage from deflection due to the weight of the ore or from equipment traffic. Selection of pad specifications and materials is determined largely by site-specific parameters such as availability of local materials (i.e., clays), slope of the site, geotechnical properties of the subbase, temperature variations, and operational considerations (i.e., single- or multiple-use pads). Single liners are believed to be the norm, although double and even triple liners are being used. Synthetic liners are often placed over a layer of compacted native clay soils.

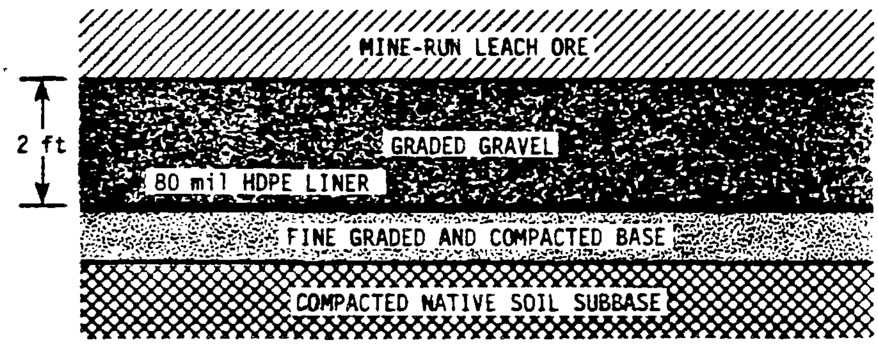
Pad construction involves clearing and grubbing the area, grading and compacting the subbase (usually with a sheep's-foot or vibratory roller), placing the liner (clay is typically placed and compacted, with added moisture, in multiple lifts, each usually 6 inches thick), and placing a layer of graded ore or gravel over the clay and synthetic liners to provide both a drainage blanket and to protect them from damage. Examples of some different types of pad construction are shown in Figure 5. Permeabilities of the subbase and clay liners are determined through compaction tests and the use of nuclear densiometers. Design engineering and construction of liners in this industry have reached a high level of sophistication. The impetus for the achievement of this competency is the fact that the process solution contains the product gold. At current prices of over $400 per ounce, loss prevention is of paramount concern to the operator.

Sizes of leach pads vary greatly. Smaller pads cover less than an acre, whereas individual pads as large as 50 acres are in use in some places. For example, Newmont Gold Company has constructed two 50-acre pads lined with 80-mil HDPE at its Gold Quarry Operation near Carlin, Nevada.

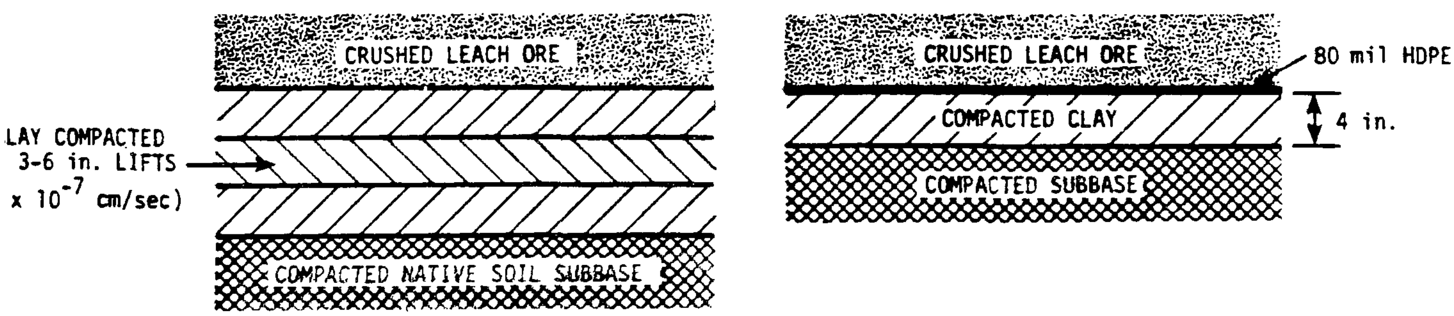
Except in valley heaps, (which are discussed later in this section), the hydraulic head on the pad is kept to a minimum; thus, the driving force pushing any potential seepage is not as great on a pad as it is, for example, in a full surface impoundment (Figure 6). Because heaps are constructed to be highly permeable, are contained only on the base, are on sloped surfaces to promote drainage, and often have drainage blankets (coarse gravel) or drain pipes over the pad, buildup of a saturated zone within the heap is minimized. Also, atmospheric oxygen is required for the efficient extraction



SMOKY VALLEY COMMON OPERATION
ROUND MOUNTAIN GOLD COMPANY



GOLD QUARRY OPERATION
CARLIN GOLD COMPANY



CANDELARIA MINE
NERCO MINERALS

Figure 5. Examples of heap leach pad construction.

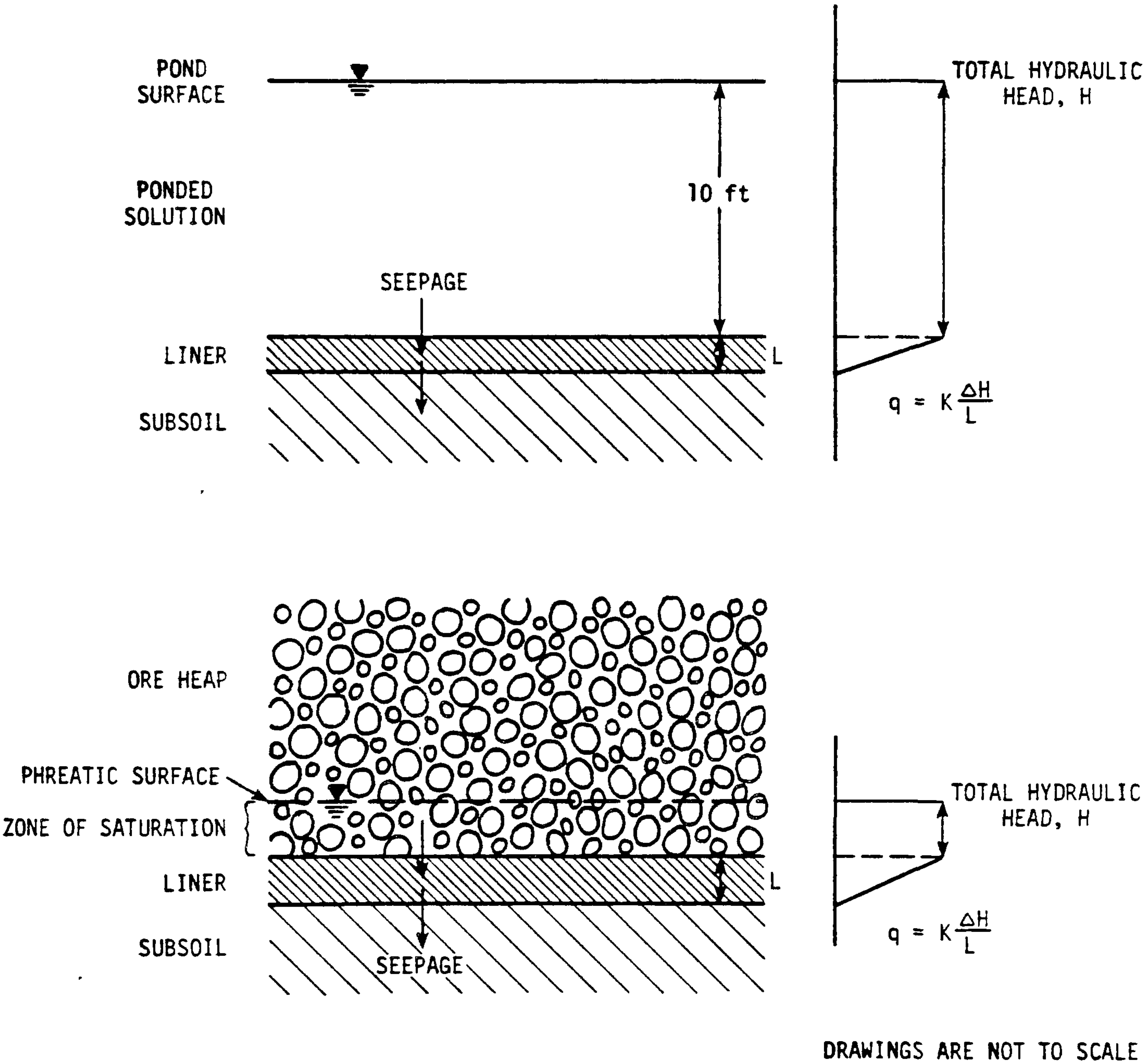


Figure 6. Relative effect of hydraulic head on seepage through pond liners and leach pads.

Source: Strachan, Clint. Geotechnical Studies II: Design and Construction. Chapter 8 in Short Course on Evaluation, Design and Operation of Precious Metal Heap Leach Projects. AIME, SME, Albuquerque, New Mexico, October 13-15, 1985.

of gold by cyanide; therefore, it is important, from an operational efficiency standpoint, to prevent inundation. In addition, if the saturated zone overlying the pad were thick enough, solution could exit the side of the heap at some point and cause erosion of the heap. Although measurements were not available, operators indicated that the zone of saturation over the pad is typically only inches thick. However, the hydraulic head on some pads, for example, the Darwin operation, can be as much as 5 feet.

Pads are either single-use, dedicated (sometimes called permanent) pads or reusable (restackable) pads. The industry norm is single-use clay or synthetic pads, although a few operations (e.g., Round Mountain Gold/Smoky Valley Common Operation, Newmont Gold Company/Maggie Creek, Gold Fields Mining Company/Ortiz and Superior Mining Company/Stibnite Operation) use reusable asphalt pads. The decision whether to use single- or multiple-use pads is based on site-specific characteristics. Considerations include the length of the leaching cycle, which is determined by ore mineralogy, and the availability of level terrain for the pad area and the spoil (leach residue) disposal sites. Homogeneous ores exhibiting consistent leach cycle times and satisfactory target recoveries are amenable to placement on reusable pads. In these cases, production schedules are set, and heaps are leached for a predetermined period of time, then rinsed, and excavated. At operations with variable ore that requires long leach times or multiple leach cycles, single-use pads are normally used. This allows leaching to continue as long as metal recoveries justify it. It also permits multiple leach cycles separated by periods of no solution application (e.g., over winter). This can permit additional oxidation of gold minerals and result in increased recoveries in subsequent leach cycles.

An example of the application of multiple-use pads is the Smoky Valley Common Operation at Round Mountain, Nevada (See Trip Report in Appendix A). At this site, a single heap covered by 30 individual solution distribution areas is constructed on two adjacent pads (1.2 million tons of ore on both pads, total). The total length of the two pads together is 3150 ft; each is 280 ft wide. Crushed ore, stacked to a height of 35 ft, is leached for 50 to 55 days, allowed to drain for 1 day, and rinsed with fresh water for 3 or 4 days. The ore is then excavated by front-end loader and hauled by truck to the adjacent spoil-disposal area. This operation moves from one end of the pad to the other and creates a 75- to 100-ft slot in the heap. One side of the slot is being excavated and removed while new ore is being added on the other. It takes 60 days for this moving slot to traverse the entire pad length. The production schedule does not allow variation in the leaching cycle.

An example of single-use pads was found at the Pinson Mining Company's Pinson Operations near Winnemucca, Nevada (see Trip Report in Appendix A). As many as 60 individual pads were originally planned at this operation. At a heap height of 20 ft, each 300-ft by 300-ft pad is capable of holding 90,000 tons of ore. The chemistry of the pregnant solution from each pad is monitored individually. This allows the leach cycle on individual pads to continue for as long as it is profitable. A total of two or three leach cycles is applied to each heap over a period of 9 months to a year. Initially, a 45- to 90-day leach recovers 55 to 60 percent of the gold values. A second leach is usually conducted after the heap has gone through a winter. An additional 2 to 5 percent of the total gold is recovered in the second leach. Depending on production schedules, a third leach cycle may be used. Although reusable asphalt pads were considered, they were not used because being able to releach the ore over extended times was desirable and because they wanted to avoid the cost of moving the ore twice. After a heap has been leached, a second lift of ore is placed on it and the cycle repeated.

Comprehensive state-of-the-art construction and quality control techniques have been developed and are being used during pad construction at the larger operations and at small operations of established companies. Competent and qualified managers and engineers direct the design and installation of these expensive systems. For example, quality control checks include frequent destruction testing of seams and materials during the installation of synthetic liners. Some small, undercapitalized operations, however, may not have adequate ability to construct pads and liners, and the integrity of these installations may be questionable.

Internal berms are sometimes constructed in leach pads. These berms, which run from side to side in the direction of the slope of the pad, internally compartmentalize large heaps. They also allow monitoring of pregnant solution chemistry (i.e., gold recovery) from different sections of the heap.

In addition, should a liner failure occur, only the leach solution applied to the area defined by the berms could escape. The application of internal berms was observed at Newmont's Gold Quarry Operation. This application is shown conceptually in Figure 7.

Selection of liner material may vary among pads at a given site. For example, Nerco Minerals installed several clay pads at the Candelaria Mine. More recently, the operator has constructed new pads on which 80-mil HDPE is placed over a compacted native soil subbase. Another example of different pad construction at the same site is the Preble Mine operated by Pinson Mining Company near Winnemucca, Nevada. Most pads at this site are constructed of native clays that have been compacted to achieve permeabilities of 10^{-7} to 10^{-8} cm/s. Because it is desirable to have a new pad ready to put in service (ready for heap construction) after the winter season ends, however, pads with synthetic liners are constructed in the fall. Synthetic liners (30-mil PVC) with a protective gravel layer can survive the winter undamaged and be put in immediate service in the spring. Whereas, unloaded clay pads would be damaged by drying and winter weather if not protected by ore heaps. Also, clay cannot be worked properly in the colder weather encountered during the period in which these pads are constructed. Because clays are available locally, however, they are the material of choice for pads constructed during the warmer months of the year.

Clays and ancient lake bottom sediments suitable (with added moisture) for use in heap leach pad construction are prevalent in the Western States.[16] On a cost basis, compacted clay liners are usually preferred over synthetics and asphalt.[17] Clay pads must be kept moist until the heap is constructed and leaching has been initiated. A clay pad that is allowed to dry will form cracks large enough for sand to blow into, and the channels so formed will not reseal themselves.[16] If this occurs, pregnant solution may be lost through seepage when leaching begins. Treating the surface of a clay pad with chemical polymer or emulsion surfactants will make it less permeable.[17] Clay pad construction costs have been reported to be in the range of \$0.40 to \$0.60 per square foot.[15] The cost of a clay pad is highly dependent on the proximity of a source of suitable clay. In contrast to the cost of clay pads, the 7-inch-thick asphalt pad at the Smoky Valley operation cost \$3.75/ft^2.[18]

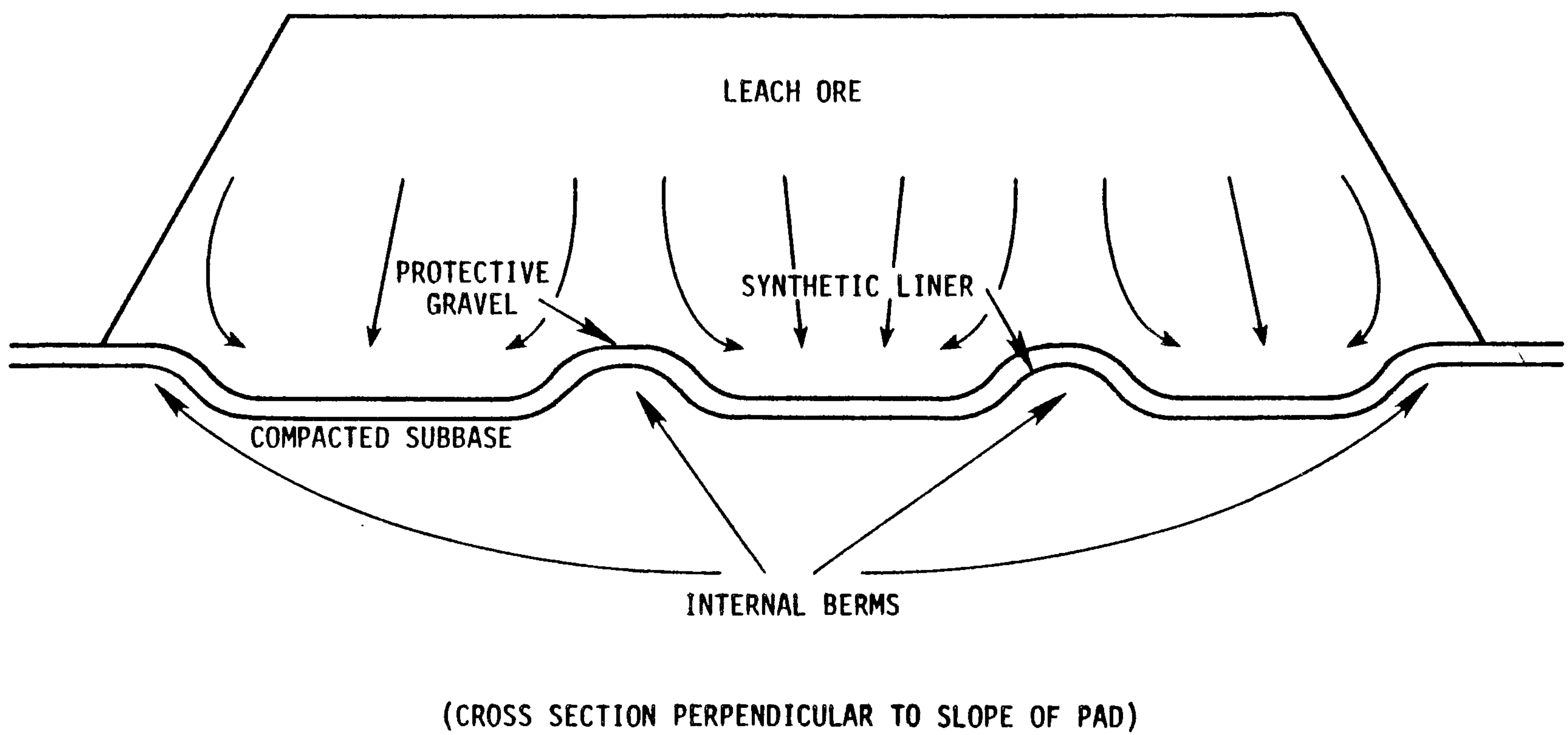


Figure 7. Conceptual diagram of internal berms on a heap leach pad.

For purposes of illustration and comparison, design and operational characteristics of several selected heap leach operations are presented in Table 4.

HEAP CONSTRUCTION

Heaps are constructed with standard earth moving equipment, such as front-end loaders, bulldozers, and haul trucks. Conveyors or radial stackers also can be used. Ore is placed with a front-end loader to a maximum height of about 16 ft, pushed up with a dozer, or dumped by truck on top of the heap. Conveyors or stackers (as used at Ortiz, for example) convey ore to the heaps and thus avoid compaction due to equipment traffic on the ore. The slope of the sides of the heaps, which are shaped like truncated pyramids, is the natural angle of repose of the ore, typically about 1:1. Heights of heaps vary from 16 ft (limit of front-end loaders) up to 200 ft.

The specific ore placement technique profoundly influences the efficiency of gold recovery from the heap.[2] Care must be taken during ore placement to avoid compacting the material, which can reduce its permeability significantly. Heap height is limited by the ability of the foundation and pad to support the weight of the heap without failure, the structural stability of the ore, and its permeability. It was once thought that leaching solutions became oxygen-deficient after percolating through about 10 ft of ore, and that gold extraction could be hindered.[2] Heaps much higher than 10 ft are now in common use, however, and achieve good recoveries.

After the ore has been leached, it is either spoiled on the pad, excavated, and removed to a spoil-disposal area or another lift of ore is placed on top of it and leaching is continued. Ideally, when multiple lifts are leached, the leach solution will percolate through all lifts and dissolve additional metal values from the lower previously leached lifts. Fine ores are generally leached in a single lift, whereas coarse material (e.g., run-of-mine ore) may be leached in multiple lifts. This is because fine ores are typically depleted after one leach cycle, and coarse ores generally take longer to leach.[2] The application of multiple lifts allows more efficient use of pad space. Characteristics of the particular ore and land availability dictate heap height, and the choice between multiple- and single-use pads.

TABLE 4. DESIGN AND OPERATIONAL CHARACTERISTICS OF SELECTED HEAP LEACHING OPERATIONS

Company/operation	Location	Ore grade, oz[a]/ton	Ore treatment	Leach pad construction	Metal recovery method	Ore processed, 1000 tons	Production, 1000 oz/yr
Amselco Minerals, Inc./Alligator Ridge	White Pine Co., NV	0.120 Au	Crush to -3/4 in.; agglomerate to -1/2 in. mine run	12 in. of compact clay	CA[b]	750	70 Au
Newmont Gold Co./Bootstrap Plant	Elko, NV	0.044 Au		Compact clay lake bed	CA	220	6 Au
Newmont Gold Co./Carlin-2	Carlin, NV		Uncrushed mine run	80-mil HDPE liner	CA	4500	
Newmont Gold Co./Maggie Creek Plant	Carlin, NV	0.03 Au	Crush to -1½ in.; agglomerate	2-ft. clay base, 5-in. asphalt layer, 2-in. rubberized asphalt membrane, seal coat	CA		
Cyprus Mines Corp./Northumberland	Austin, NV	0.080 Au 0.400 Ag					40 Au 70 Ag
Fischer Watt-Pecos Resources/ Tuscarora	Elko Co., NV	0.020 Au 1.75 Ag	Uncrushed mine run (fines to 6 in.)	Wet, compacted, lake-bed clays	MC[c]	100	1 Au 70 Ag
NERCO Metals, Inc./Candelaria	Mineral, NV	Minor Au 3.15 Ag	Crush to -1 in.; agglomerate	18-in. compacted clay or 80-mil HDPE	MC	2000	>2000 Ag
Pegasus Explorations, Ltd./ Zortman-Landusky	Zortman, MT	0.066 Au	Uncrushed mine run	12 in. of compacted bentonitis shale and 30-mil PVC	MC	3640	70 Au 125 Ag
Pinson Mining Co./Pinson Mine	Winnemucca, NV	0.02-0.03 Au	Uncrushed mine run	12 in. of compacted clay			
Pinson Mining Co./Preble Mine	Winnemucca, NV	0.062 Au	Crush and agglomerate	12 in. of compacted clay or 30-mil PVC	CA		
Saratoga Mines, Inc./Saratoga	Central City, CO	0.04-0.10 Au	Crush to -1¼ in., agglomerate	6 in. of compacted tailings and 30-mil PVC	MC	125	3 Au 10 Ag
Round Mountain Gold Corp./Smoky Valley	Round Mountain, NV	0.03-0.04 Au	Crush to -1/2 in.	3 in. of rubberized asphalt, 4 in. of asphalt	CA	2000	60 Au 30 Ag
Superior Mining Co./Stibnite Mine	Yellow Pine, ID	0.05-0.08 Au	Crush to 1.25 in.	3 in. of sealed asphalt, coarse geotextile fabric, 1 ft of gravel, 30-mil PVC liner	CA	400-500	25-30 Au

TABLE 4 (continued)

Company/operation	Location	Ore grade, oz[a]/ton	Ore treatment	Leach pad construction	Metal recovery method	Ore processed, 1000 tons	Production, 1000 oz/yr
Tenneco Minerals Co./Borealis	Mineral, NV	0.090 Au 0.544 Ag	Crush to -2 in.; agglomerate	5-in. of compact asphalt	MC	450	30
The Anaconda Co./Darwin	Darwin, CA	Minor Au 1.38 Ag	Agglomerate tailings	18-in. of compacted soil and clay	MC		
The Standard Slag Co./Atlanta Mine	Lincoln Co., NV		Crush to -0.25 to 0.50 in.		MC	120-135	
Windfall Venture/Windfall	Eureka, NV	0.028 Au Minor Ag	Uncrushed mine ore	2 in. of compact asphalt	CA	220	5 Au

[a]Oz = troy ounces throughout table
[b]Carbon adsorption
[c]Merrill-Crowe

Construction techniques vary from site to site and are altered at any given site as better means are developed or if ore characteristics change as the ore body is developed. For example, Pinson Mining Company originally planned 60 individual adjacent single-lift heaps, each with a height of about 16 ft. During construction and operation of the heaps, it was determined that two additional lifts could be placed after the top of the previously-leached material was scarified. The benefits of this multiple-lift method are additional gold recoveries from releaching lower lifts and lower pad construction costs because more ore can be treated on any given pad. As another example, heap construction at the NERCo Minerals Candelaria Mine has involved placement of seven contiguous heaps, each about 1200 ft long, 200 ft wide, and 20 ft high. After leaching is completed on each heap (45 to 60 days), the surface is scarified and another lift is placed on top of it. Each lift of ore is placed by truck and dozer to a height of 25 ft. The top 5 ft is then pushed off to remove any material compacted by the equipment. The ultimate height of the heap will be 110 ft. Another example is the Carlin-2 operation of Newmont Gold Company, where two 50-acre pads have been constructed. Run-of-mine ore is stacked in a single lift, to a height of 50 ft. Additional lifts may be added in the future, which will result in an ultimate heap height of 200 ft.

SOLUTION HANDLING/LEACH CYCLE

A schematic flow diagram of the path taken by leach solutions is shown in Figure 8, and the characteristics of the solutions and the construction of impoundments are discussed in the paragraphs that follow.

Leach solutions basically consist of sodium cyanide, caustic (i.e., lime), and water. Antiscaling additives are sometimes used to prevent fouling of the sprinkler heads. Sodium cyanide, the only commercially proven lixiviant, is added to maintain a concentration in the barren solution of about 0.5 lb per ton of solution (approximately 250 ppm CN). Caustic (usually lime, caustic soda, or sodium hydroxide) is added to maintain the alkaline pH of the barren solution.

Most operations have a net water loss due to evaporation (as much as 10 percent) and require the addition of fresh water for makeup. Makeup water is typically obtained from wells installed for that purpose. The solution

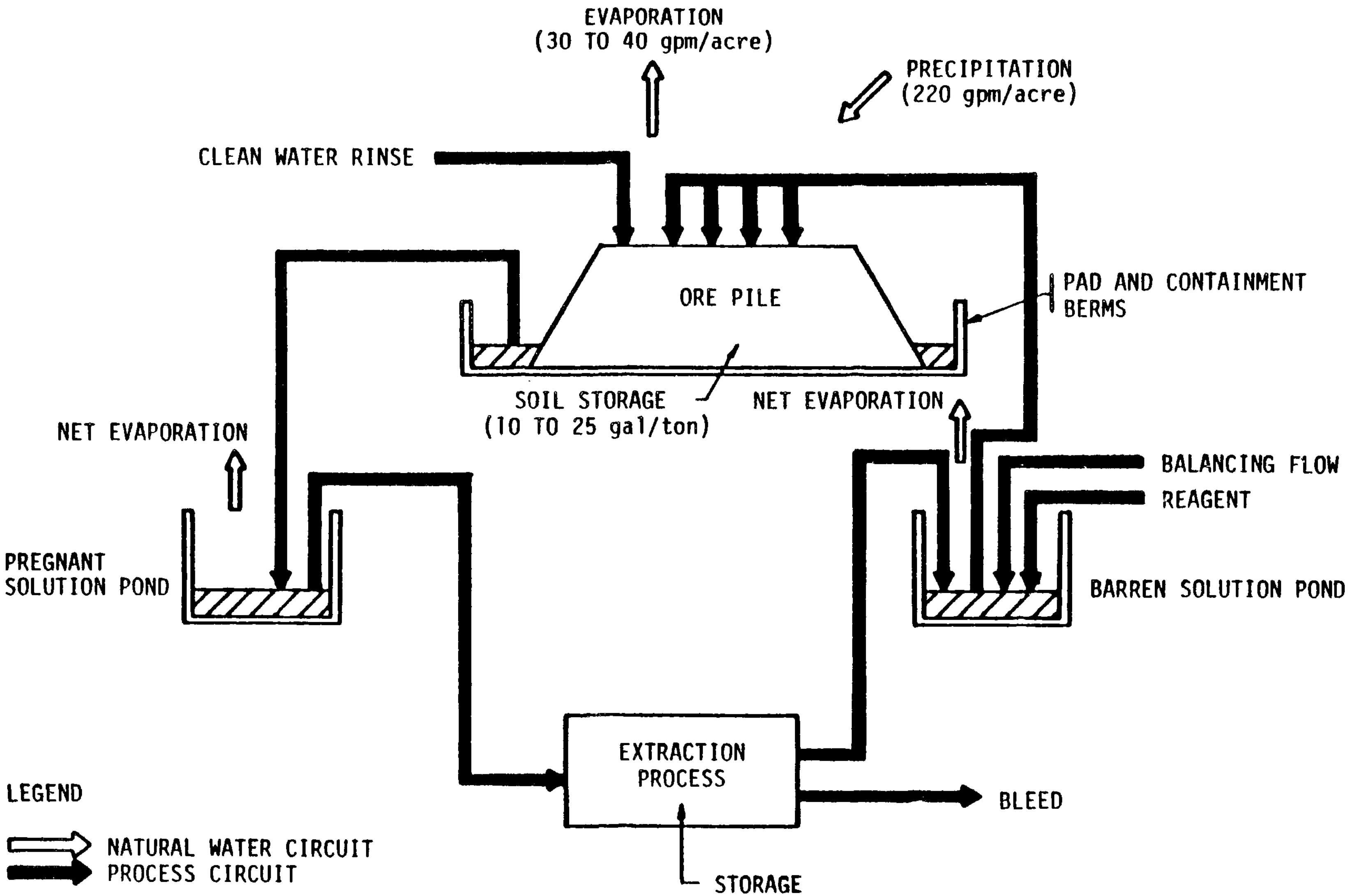


Figure 8. Schematic flow diagram of leach solutions at a typical heap leach operation.
Source: Hutchinson, Ian. Surface Water Control. Chapter 9 in Short Course on Evaluation, Design, and Operation of Precious Metal Heap Leach Projects. AIME, SME, Albuquerque, New Mexico, October 13-15, 1985.

management systems are designed to be a closed-loop recycle with no discharge of effluents during operations. Some operations may discharge treated bleed streams (under NPDES permit), however, if they have a net water gain as a result of local climatic conditions.

The barren solution is sprayed onto the surface of the heap. Plastic pipes distribute the solution to impulse (rainbird) or wobbler-type sprinklers. These sprinklers are favored because they distribute the solution evenly and produce a large droplet, which minimizes evaporation. Sprinklers are usually placed on 40-ft centers over the top of the heap. The typical solution application rate is 0.005 gallon per minute/ft^2. This operation is monitored to ensure that the sprinklers are functioning, that they do not become stuck in one position, and that no ponding of solution occurs on the surface. Ponding indicates the application rate is too great or that a zone of low permeability exists. In either case, efforts are made to correct the situation by reducing the solution application rate or by scarifying the top of the heap.

Moisture content in run-of-mine ore varies, but levels in the 5 to 10 percent by weight range could be considered typical. Solution applied to a fresh heap percolates through the ore, flowing over ore particles and into cracks and crevices by capillary action. Sufficient solution must be applied to saturate the heap and overcome its storage capacity before any solution can drain from the heap. Storage capacity of the heap is determined by the porosity and quantity of the ore in the heap. When saturated, the moisture content is typically in the range of 10 to 15 percent by weight. Solution equivalent to 10 percent of the weight of the ore may be required to wet the heap, and an additional 10 percent may be stored in the heap during steady-state leaching.[19] For example, the 20-ft-high heaps at the Pinson operation contain about 90,000 tons of run-of-mine ore. Initial breakthrough of solution occurs about 18 hours after solution application begins (application rate is 0.005 gallon per minute/ft^2) and a steady-state flow is achieved after about 72 hours. Based on site measurements, about 250,000 gallons are required to saturate an individual heap. When heaps are idled over winter at this site and releached in the spring, the same storage capacity is noted.

The volume of pregnant solution leaving the heap under steady-state leaching conditions is a function of the area of the top of the heap, the solution application rate, and the evaporation rate. A small heap having 40,000 ft^2 of surface area, for example, would generate a maximum of 200 gallons per minute, assuming no losses (40,000 ft^2 x 0.005 gallon per minute/ft^2). The 50-acre heap at Carlin's Gold Quarry Operation generates a flow of 4000 gallons per minute under steady state conditions.

The chemistry of the pregnant solution differs from that of the barren spray. Concentrations of gold are measured in hundredths of an ounce per ton of pregnant solution. The pregnant solution at Round Mountain, for example, contains about 0.04 oz/ton of solution (about 1.2 ppm). The pH of the pregnant solution is usually lower than the barren spray because of the neutralization that occurs in the heap and CO_2 pickup from the atmosphere. In the case of agglomerated ore, however, the pH of the pregnant solution may be the same or higher as that of the barren spray because of the alkalinity imparted by the cement used as the binder.

The free cyanide content is also lower in the pregnant solution because some cyanide volatilizes at the surface of the heap. Cyanide percolating through the heap is also tied up in metal complexes (e.g., with iron), is destroyed by cyanicides present in the ore, is bound by carbon present in the ore, or is otherwise consumed. To maintain the typical 1 pound of cyanide per ton of solution concentration in the barren spray that is necessary for efficient leaching requires the addition of an amount of cyanide equal to its consumption in the heap. At the sites visited during the project, reagent usage reportedly varies from 0.1 to 0.3 pound of NaCN per ton of ore (see Appendix A), but 0.5 lb/ton may be closer to the industry average. Caustic in the form of lime is added to the barren liquid at a rate of 0.3 lb/ton of ore at two of the sites visited.

The pregnant solution flows down-slope over the leach pad to a lined collection ditch. Collection ditches are situated along one or two sides of the pad, depending on the pad's slope. If the pad slopes to one side, the collection ditch is located along that side. If the pad slopes to a corner, the ditch is located along both sides joining at that corner. Collection ditches, like leach pads, are lined to prevent loss of pregnant solution. If the leach pad is constructed with a synthetic liner, the collection ditch is lined with a continuation of the same material or a different thickness of the same material. If the leach pad liner is constructed of compacted clay, the ditch is lined with a synthetic material that is keyed into the pad. In the case of asphalt pads, the collection ditches are continuous with the pad and are constructed of asphalt.

The pregnant solution flows by gravity through the lined collection ditch to a lined surface impoundment, known as the pregnant solution pond. This impoundment is normally situated adjacent to and immediately downgrade from the heap. The industry standard is believed to be the use of synthetic single liners placed over a compacted subbase of native soils or clays. Observation ports are installed under all leach ponds in Nevada in order to detect seepage through pond liners. Groundwater monitoring around solution ponds varies in extent and sophistication. The pregnant solution pond is the largest of the surface impoundments used in the operation because it must be able to hold not only the normal flow of pregnant solution, but also any additional flow due to normal rainfall or unusual (i.e., 100-yr) storm events and still provide sufficient freeboard to prevent overtopping. Thus, the dimensions of the pregnant solution pond are a function of the size of the heap and the climate at the site. These ponds are typically 10 to 20 ft deep and have side slopes of 3:1 (h:v). For instance, Candelaria's pond has a capacity of 9 million gallons and 2.4 acres of surface area.

Typically, an emergency overflow basin is situated immediately downgrade from the pregnant solution pond. This basin may be lined with a synthetic, as at Candelaria, or it may be constructed of native clays or unlined. Its function is to provide emergency containment of any overtopping of the pregnant solution pond.

Pregnant solution is pumped to the precious metal recovery process, where gold or silver is removed. The barren solution is usually sent to a barren solution pond, which may be about half the size of the pregnant solution pond. Some sites (e.g., Mesquite) do not use a barrens pond. Construction of the barren pond is the same as that of the pregnant pond--synthetic liners placed over compacted earth. The barren solution is treated with cyanide and caustic, as discussed previously, as it is pumped back to the heap. The heap leach system often has a total residence time of more than 3 days.[19]

Solution application often must be curtailed or halted during winter because of ice formation. Some sites heat the barren solution to allow leaching to continue during mild winter conditions, which extends the leaching season. Other sites have developed application methods (e.g., subsurface solution application from distribution pipes buried in the heap and spraying to produce ice domes), which allow leaching to continue during winter, albeit at reduced rates. The impact of winter on heap leach operations is more pronounced in northern climates (e.g., Montana) than in the Southwest.

Leaching operations also may be interrupted for other reasons. Some facilities may operate only intermittently to allow oxidation to occur in the heap, which permits additional gold values to be recovered. Still others may operate in this manner because they are undercapitalized or only part-time business ventures.

METAL RECOVERY

Precious metals in the pregnant solution are recovered either by adsorption on activated carbon or by Merrill-Crowe zinc dust precipitation. Unconventional recovery processes, such as ion exchange, solvent extraction, and direct electrowinning, also may be applicable in special circumstances. The choice between carbon adsorption and zinc precipitation is usually based on processing cost and on the gold/silver content of the pregnant solution.[20] The zinc dust precipitation method is usually preferred at large operations where the silver/gold ratio exceeds two or where the concentration exceeds 2 ppm.[20] Carbon adsorption is the method of choice at smaller operations because it costs less.[20]

The Merrill-Crowe zinc dust precipitation process involves four major process steps:

1) Clarification of pregnant solution to achieve efficient precipitation.

2) Vacuum deaeration to remove dissolved oxygen, which causes passivation of the zinc surface, and carbon dioxide, which can react to form calcium carbonate that blinds filters.

3) Addition of lead salts to remove sulfides prior to precipitation of precious metals with powdered zinc.

4) Filtration of precipitates, which are typically dried, fluxed, and smelted to form a gold or silver bullion. The barren solution is returned to the heap.

The carbon adsorption process involves three unit operations:

1) Loading the precious metals from the pregnant solution onto the activated carbon. This is normally accomplished in a series of countercurrent tanks. The barren solution is returned to the heap.

2) The gold/silver is eluted, usually with a hot caustic cyanide solution. The stripped carbon is regenerated by steam or thermal reactivation.

3) The gold/silver is recovered from the concentrated cyanide solution by electrowinning, followed by fire refining to produce dore bullion. Zinc dust precipitation can also be used.

Assuming a 1 ppm content in the pregnant solution, the carbon adsorption method would produce an ounce of gold at a cost of about $7.50.[15] The Merrill-Crowe method would entail production costs of between $6.00 and $8.20 per ounce.[15]

RESIDUE DISPOSAL AND SITE CLOSURE

Heap leach residue, the barren ore remaining after obtainable gold values have been extracted, is either left in place (i.e., spoiled on the pad) or excavated, hauled by truck, and disposed of in an onsite disposal area. At the majority of sites, the leach residue currently generated is left on the pads at closure.

At closure, the smallest heap would be less than an acre in size and 16 ft or less in height. Such a heap would be generated by a small-scale, short-term venture. One of the largest heaps would be 50 or more acres in size and 100 to 200 ft in height. A large heap such as this would have been generated by a large-scale operation that processed the ore over a period of years and added multiple lifts to the heap. Only at those sites using reusable pads is the leach residue removed from the pad. At these sites, the process of removing the leach residue from the pads and disposing of it is continuous over the active life of the site.

Standard industry practice is to follow the leaching of an individual heap with a drainage period lasting 1 or more days, during which no solution is applied. The heap is then rinsed with fresh water for several days. For example, the State of Nevada requires rinsing until a preset limit (i.e., a pH of 8.5 and a cyanide content of 0.2 ppm) is achieved in the rinse water. The barren solution remaining at the time leaching is ceased is allowed to evaporate to dryness (if the climate permits) or is treated with a cyanicide. Again in Nevada, for example, no discharge of solution is permitted and the barren solution is lost to evaporation.

As documented in previous reports, essentially no data are available on the quantity of cyanide remaining in heap leach residue.[21] How effective a short-term rinsing with fresh water is in removing all free cyanide from the residue has not been demonstrated. The addition of a cyanicide (such as hypochlorite) to rinse water has been documented at three sites (Annie Creek, Stibnite, and Darwin). Again, the effectiveness of this treatment is largely unknown.

Leach residue disposal at sites that have reusable pads is accomplished by excavating the residue after it has been drained and rinsed with fresh water, loading it into trucks, and hauling it a short distance to a dump area. The residue is end-dumped from the top of the disposal pile and cascades over the outer face of the pile. This spreads the residue out in a thin layer that dries rapidly. This method of disposal was observed at both the Smoky Valley and Carlin-2 operations. Free cyanide left in the residue probably would volatilize and escape to the atmosphere.

Operations of one of the larger sites visited (Candelaria) indicated that at closure, heaps will be rinsed as discussed earlier, and any solution remaining in the impoundments (pregnant and barren ponds) will be evaporated to dryness as specified in their permit. Collection ditch liners and other exposed liner material around the heap will be removed and placed in the empty impoundment. The impoundment liner will then be folded over on itself and buried in place.

After closure, the liners beneath heaps would afford little protection against leachate seepage. Any leachate formed in the heap would flow downward over the liner and run off the end of the liner onto the ground. If ditch and impoundment liners were left in place, the leachate would collect in the pregnant pond, where it would evaporate or leak to the ground if the liner should fail over time. The generation of leachate after closure is a function of the rates of precipitation and evaporation and the water retention characteristics of the spoil. (Additional discussion on leachate formation is presented in Section 5.6.)

SITE SECURITY

Security is provided by guard houses, locked gates, and perimeter fencing. In particular, pregnant and barren solution ponds are surrounded by fencing, and signs are posted to warn of the presence of cyanide. In arid areas, the presence of surface water is a strong attraction to passing animals, especially when the nearest surface water may be five or more miles away. Operators often construct fresh water ponds at a location away from the production area to provide a drinking water source, thereby lessening the chance that animals would attempt to gain access to and drink the cyanide solutions in the pregnant or barren solution ponds or collection ditch. Flags and netting are also used to discourage birds from using solution ponds and ditches at some sites.

VALLEY LEACH

Heap leaching has been conducted in areas where relatively flat native terrain was not available by constructing and grading a waste rock or overburden fill to form the necessary surface. The Nevex Mine near Carson City, Nevada, is operating a heap constructed in this manner. More recently, an approach called "valley leach" has been used for heap leaching operations in moderate to steep terrain. Valley leach is a modification of heap leaching that is applicable in steep terrain where typical heaps cannot be constructed. The system involves construction of a containment dike by using compacted waste rock at the downhill limit of the heap and placement of a liner over the upstream face of the dike and over the pad area above it.[22] The heap is then constructed behind the dike. The major difference between a valley leach and a typical heap leach operation is that a pregnant solution pond is not constructed in the valley leach system unless the cyanicides in the ore necessitate the use of an external pond. The pregnant solution is stored internally in the heap (in the voids of the ore) and contained by the containment dike and liner. A conceptual diagram of a valley leach system is shown in Figure 9. A valley leach system requires a durable ore (one that will not break down upon leaching) for stability. It also requires a high-integrity liner (usually a double liner, synthetic over clay, for example) because of the hydraulic head imparted by the internal storage of pregnant

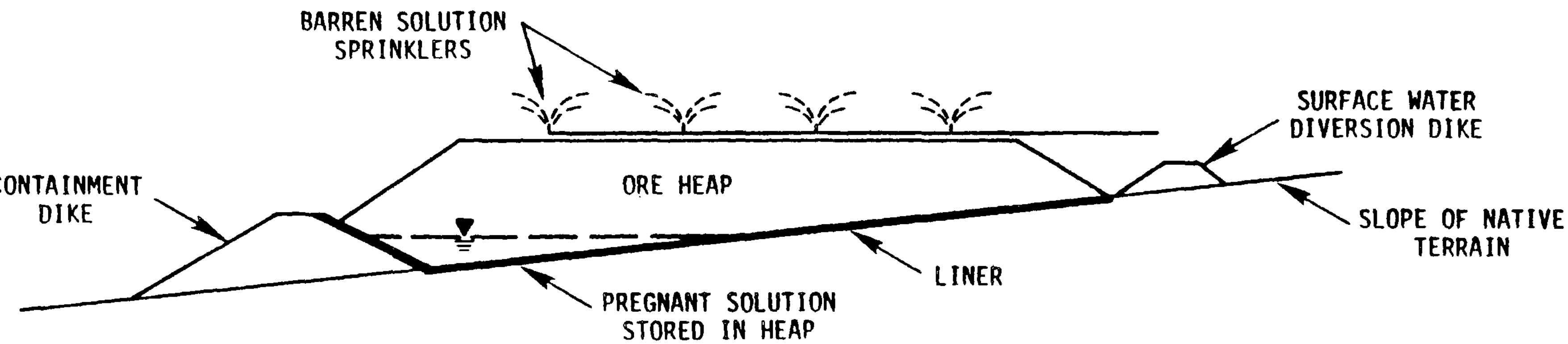


Figure 9. Typical cross-section of a valley leach type heap.

Source: Ref. 22.

solution. The strength of the foundation, the clay liner, and the clay/synthetic liner interface must be assessed to determine safe loading and slope limits.[22] Pregnant solution is extracted either by pumping wells or by gravity through valved pipes passing through the containment dike. Valley leach systems have been used at the Zortman/Landusky operation of Pegasus Gold in Montana and the Summitville Mine of Galactic Resource in Colorado.

SECTION 4

SUMMARY OF THE TOXICITY AND MOBILITY OF CYANIDE

This section includes a brief discussion of the available information on cyanides present in process solutions and leach residues, the toxicity associated with various forms of cyanide, and the potential for migration of cyanides from heap leach operations and leach residues. A considerable data base is available on cyanides from mining operations and the environment. Very little data are available, however, on the types or quantities of cyanides in heap leach residue. The following discussion is meant to be generic to allow the reader, especially anyone unfamiliar with the topic, to put information presented in previous sections and the conceptual controls discussed in the following section in context.

CYANIDE IN PROCESS SOLUTIONS

Typically for gold leaching, sodium cyanide is added to the barren solution to maintain a concentration of about 0.5 pound per ton of solution. This equates to about 250 ppm. The protective alkalinity is maintained in the barren solution pond by the addition of lime, and a pH between 9 and 11 is maintained. Under these conditions, the cyanide present is mostly free cyanide, as required in the leaching reaction. The barren solution pond typically holds hundreds of thousands of gallons of this solution. The pregnant solution pond contains lesser concentrations of free cyanides because of the destruction, losses, and complexation that occur in the heap; however, a significant concentration of free cyanide is still present. The solution in these surface impoundments represents the greatest source of free cyanide at a leach operation. Failure of the containment system, liner failure, or overtopping of the pond would result in free cyanide in an alkaline solution being released to the environment.

CYANIDE IN LEACH RESIDUE

Cyanide in leach residue occurs in combinations of various metallo-cyanide complexes, cyanates, and free cyanide (HCN and CN^- ion). Several metallo-cyanide complexes can occur in leach heaps. Some of these are strongly bound and stable, some are moderately bound and dissociate with time, and some other forms dissociate easily. As the metallo-cyanide complexes dissociate, they may form different metallo-cyanide complexes as well as free cyanide (HCN and CN^- ion). Strong metallo-complexes include those of iron, cobalt, and gold [$Fe(NC)_6^{-4}$, $CO(CN)_6^{-4}$ and $Au(CN)_2^{-1}$].[21] Moderately strong complexes include those of copper, nickel, mercury, and silver [$Cu(CN)_2^{-1}$, $Cu(CN)_3^{-2}$, $NI(CN)_4^{-2}$, and $Ag(CN)_2^{-1}$]. Weak complexes include those of zinc and cadmium [$Zn(CN)_4^{-2}$, $Cd(CN)_3^{-1}$, $Cd(NC)_4^{-2}$]. The complexes that are formed in a given heap are determined by the mineralogy of the ore. As metallo-cyanide complexes dissociate, they may form other complex ions and free cyanide. Depending on the pH, the free cyanides can be released to the atmosphere or leached with rainwater. If the pH of the heap leach is less than 9, some or most of the free cyanide will be released to the atmosphere. If the pH is greater than 9, free cyanide will remain in solution. Low concentrations of soluble free cyanides are amenable to biodegradation. High concentrations of free cyanide are not easily biodegraded, however, and could result in cyanide contamination in runoff or in liquids percolating to underlying soils and ground water. During gold heap leaching an alkaline pH (9 to 11) is maintained, but afterwards the piles are usually rinsed with fresh water and the pH approaches a more neutral range; thus, much of the free cyanide can be volatilized. Leach residue near the surface of the heap can become less alkaline with the absorption of CO_2 from the atmosphere. If the heap is not rinsed or rinsing is inadequate, the solution remaining in the interior of the heap may remain alkaline and be a potential source of free cyanide. Concentrations of cyanide in heap leach residue vary with the ore composition, the pH of the residue, treatment of the residue (i.e., water or chlorine rinses), age of the residue, and environmental factors such as the amount of rainfall, temperature, and degree of aeration.

Ore mineralogy affects the types of complexes formed, which determines their long-term stability, as previously discussed. The pH of the residue affects the rate of release of cyanides from the heap as volatilized HCN, solubilized free cyanide, or metallo-cyanide complexes. Few researchers have described the effects of treatments such as fresh water rinse and treatment with hypochlorite on cyanide concentrations in the heap; however, alkaline rinses, water rinses, and rinses with oxidizing agents are some of the methods that may be used to increase rates of destruction of free cyanide and thus more quickly reduce the cyanide concentrations remaining in the heap leach residue. For example, the State of Nevada requires that leach residue be rinsed with fresh water until the pH of the solution exiting the heap is 8.5 or until the cyanide concentration is below 0.2 mg/liter.

Few data are available on the content and fate of cyanide in heap leach residue. Available data indicate that cyanide in heap leach residue decreases over time. As part of a study on the long-term degradation of cyanide in an inactive heap, Engelhardt measured total and free cyanide concentrations at various depths and locations in a heap over an 18-month period.[23] He found that free cyanide concentrations varied from about 8 mg/kg to nearly 200 mg/kg in core samples taken 3 months after leaching had been terminated. At the end of 18 months, free cyanide concentrations were below 40 mg/kg, which indicated an approximate decrease of 85 percent in free cyanide concentrations over the 1½-year study duration. It was also found that free cyanide concentrations in heap samples were only slightly less than total concentrations. In two other studies, Schmidt et al. reported 65 percent decreases in total cyanide over a 70-hour residence time in a tailings pond.[25,26] Ely documented cyanide in leach residue and soil at the American Mine. Contamination was limited to a depth of less than 24 inches in the soil at this site where liner failure had occurred.[24]

Several environmental factors influence the rate of degradation of cyanide in heap leach residue. Intermittent rainfall and higher temperatures are both conducive to increased release of cyanide and degradation within the heap. Mixing of the material that occurs when leach residue is spoiled (disposed of) off the pad enhances cyanide degradation. As leach residues are aerated, they become more neutral and less alkaline through absorption of carbon dioxide from the atmosphere. As the pH decreases, cyanide is increasingly volatilized as HCN. In solution below pH 7, essentially all the free cyanide is present as HCN and equilibrium is maintained with atmospheric HCN vapor. The free cyanide/pH relationship is shown in Figure 10.

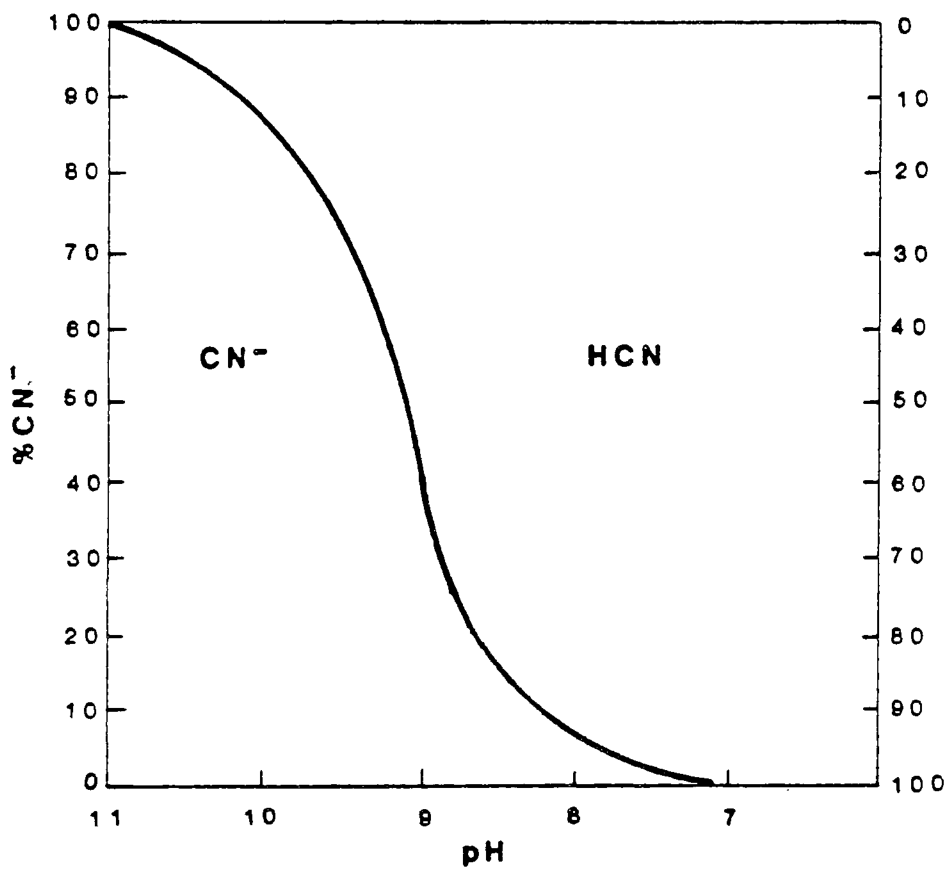


Figure 10. Effect of pH on dissociation of hydrogen cyanide.

(Source: Workshop - Cyanide From Mineral Processing. Utah Mining and Mineral Resources Research Institute. J. L. Huiatt, ed. 1982.)

TOXICITY OF CYANIDE

The toxicity of cyanide varies widely with the form of the cyanide. Free cyanide in the form of HCN is the most toxic; many metallo-cyanide complexes are far less toxic.[27] The toxicity of metallo-cyanide complexes in the aquatic environment varies with the stability of the complexes. Those that dissociate readily to release free cyanide, such as zinc and cadmium cyanide complexes, are highly toxic. Others that exhibit moderate dissociation are less toxic; these include copper and nickel cyanide complexes. Iron and cobalt complexes are tightly bound and are considered to be nontoxic.[27] Complexing cyanides in receiving streams has been suggested as a means of reducing toxicity due to cyanides.[27] In 1985, however, Heming and Thurston reported that ferrocyanide and ferricyanide were more acutely toxic to rainbow trout when tested in light than in the dark because of the tendency of these iron-cyanide complexes to decompose under sunlight to release free cyanide.[28] Both ferrocyanide [$Fe(CN)_6^{-4}$] and ferricyanide [$Fe(CN)_6^{-3}$] are byproducts of the cyanidation processes for gold extraction.

Cyanide in the form of HCN is a respiratory or cellular asphyxiant that prevents tissues from utilizing oxygen. Depression of the central nervous system, the tissue most sensitive to hypoxia (oxygen deficiency), can result from exposure to HCN.

In humans, cyanide can be absorbed through the skin, mucous membranes, and by inhalation. Alkali salts are toxic only upon ingestion.[30] Inhalation of cyanide fumes can be rapidly fatal depending on concentration. The nonvolatile cyanide salts seem to be nontoxic systemically, as long as they are not ingested and the formation of hydrocyanic acid is prevented.[30] Exposure to small amounts of cyanide compounds over long periods of time may cause loss of appetite, headache, weakness, nausea, dizziness, and irritation of the upper respiratory tract and eyes.[29]

Free cyanide concentrations of 0.05 to 0.10 mg/liter can be fatal to many fish, and levels as low as 0.01 mg/liter have had adverse effects on fish.[30] The EPA has established an ambient concentration of 0.005 mg/liter in surface water as the criterion level to protect fresh-water and marine aquatic life and wildlife.[21] Cyanide toxicity to aquatic organisms is due mainly to HCN derived from dissociation and hydrolysis of cyanide compounds. Thus, both the free cyanide (as HCN) concentration, which produces the toxic effects, and any cyanide complexes, which have the potential to release free cyanides as HCN through degradation, are important.[21]

Thiocyanate is a degradation or reaction product that exists in leach residue. Thiocyanate is much less toxic to humans than free cyanide. However, thiocyanate has been found to be acutely toxic to trout.

MIGRATION OF CYANIDE

Cyanide from leach residues can migrate through release to air, ground and surface waters, and to soils. The principal transport process for free cyanide (HCN and CN^-) in mining wastes is through volatilization as HCN to the atmosphere.[21] The alkalinity of leach residues is reduced near the surface through absorption of carbon dioxide, which decreases the pH of the residue and increases the volatilization of cyanide in the form of HCN. The literature review yielded only limited amount of information on free cyanide concentrations in the atmosphere. Stampfli conducted air monitoring at distances of 10 to 100 meters around a leach heap that had been deactivated by flushing hypochlorite solution and then water through the residue.[21] Cyanide concentrations in air ranged from 2 to 259 $\mu g/m^3$, and most samples showed less than 92 $\mu g/m^3$. (The TLV for cyanides in air is 10 mg/m^3.) As would be expected, Stampfli found that cyanide levels decrease as wind speeds increase; levels also decreased at greater distances from the heap piles. Several references cite volatilization as the most significant route of release of cyanide from leach residues. No reference documents any health problem related to atmospheric releases of cyanide from leach piles. Documented sampling data are not available on the release of cyanide to the atmosphere from heap leach operations and heap leach residue. The remote location of most heap leach operations, however, would tend to minimize the likelihood of adverse human health impacts.

The secondary transport process for free cyanide and soluble metallo-cyanide complexes is leaching. Zinc and cadmium cyanide complexes are more amenable to solubilization than most cyanide metallo-complexes. If the pH of solution retained in the leach spoil remains above 9 (e.g., because of inadequate rinsing), free cyanide can remain in solution and potentially could be transported to surface water or ground water through runoff and/or percolation.

Some data indicate that cyanides migrate only short distances in soils and sediments. The distance of migration varies with the type of soil and the form of cyanide. McGrew measured total cyanide in clay beneath leach and found that all the cyanide was confined to the first four inches of clay.[21] Ely's study of the American Mine indicated cyanide contamination of soil beneath ruptured liners was limited to the top 24 inches.[24] Free cyanides have the potential to migrate through saturated and unsaturated soils, but transport is limited by complexing between the soils and the cyanide compounds and by sorption onto clays or organics in the soil. Low levels of cyanides can be metabolized by microbes.[27] In aerobic soil zones, cyanides can be decreased by microbial nitrification. In anaerobic soil zones, cyanide is attenuated by sorption and precipitated as metallo-cyanide complexes, with some microbial denitrification. Transport of cyanides can occur in sandy soils or soils low in organic content.[27] Migration is limited in soils with a high clay content; soils with hydrous oxides of iron, manganese, aluminum, and other metals; and soils with high organic content.[27]

SUMMARY

Cyanide can be highly toxic or relatively innocuous depending on its species. The species of cyanide and cyanate present are determined by the physical and chemical environment and by the compositional characteristics of the ore. During active leaching, an alkaline pH is maintained to promote the existence of free cyanide necessary for the leaching reaction. After leaching and rinsing, natural mechanisms act to degrade and/or complex the cyanide remaining in the spoil. Few data are available on the content and fate of cyanide or cyanates in heap leach spoil. The principal transport mechanism is reported to be volatilization to the atmosphere as HCN. Although the acute toxicity of HCN is well documented, no problems with atmospheric releases of HCN from heap leach residue have been documented. Secondary transport is via runoff or percolation. Available data indicate that cyanides migrate only short distances in soils.

SECTION 5

ALTERNATIVE MANAGEMENT PRACTICES

Based on our understanding of the objective of this task and our knowledge of the industry, we have determined that only a limited number of alternative management practices could be applied to minimize the potential for cyanide releases from heap leach operations (both during and after leaching operations). These include alternative liner construction, oxidation of cyanide during post-leaching flush-out, and use of reagents other than cyanide. In the first place, most heap leach operations are relatively small, and their only discrete sources of potential releases are the heaps themselves and the two process solution ponds. After cessation of operations, only the heap remains as a potential source, as the ponds must be emptied during closure. Secondly, most obvious controls, such as pond and leach pad liners, surface water diversions, and post-leach rinsing, are already standard practices in the industry.

Although a relatively small number of potential alternative practices that are currently in use at some sites could be used more widely in this industry segment, their application and cost would have to be determined on a site-by-site basis because of differences in ore mineralogy, topography, geology, hydrogeology, climate, and design and operational characteristics. Economic considerations (the cost of the practice and how it affects the profitability of the operation) also are site specific. Control options applicable to an operation located in a very arid area situated over deep ground water and away from surface water or population would differ from those suitable for a site situated over relatively shallow ground water and near a population center or surface waters.

The current EPA policy regarding active heap leach piles and leach liquors is that these materials do not represent wastes, but rather are raw materials used in the production process and products, respectively (51 Fed. Reg. 24496). Only the leach liquor that escapes from the production process and abandoned heap leach piles is considered a waste material. This position has influenced the definition and evaluation of alternative management practices.

The applicability of an alternative management practice is determined primarily by the operational phase during which it will be used. Four operational phases are listed here:

- Preoperations - This phase includes site characterizations; determination of engineering, design, and operational parameters; and construction of the facility. Potential for environmental impact is assessed, and appropriate controls are designed to satisfy permit requirements.
- Active operations - This phase covers the leaching cycle, which may vary from 1 or 2 months to 3 or more years.
- Closure - This phase covers the period immediately following cessation of leaching, during which the site is brought to the condition in which it will remain.
- Post-closure - This phase is the period, usually 30 years for RCRA programs, following site closure, during which primary activities are monitoring and maintenance of the site.

Inadequate data are available for a quantitative assessment of the cyanide content in leach residue and releases from heap leach operations.[21] Information on actual releases is also sketchy. Therefore, the need for controls beyond those currently in use has not been demonstrated. The goal of this effort was to evaluate conceptual management practices that could prevent or mitigate actual or potential seepage from the heaps, leach residue, or solution ponds. The conceptual management practices evaluated are categorized in the following list according to the operational phase of a heap leach facility.

Operational phase	Management practice
Preoperations	° Installation of a system of French drains beneath the pad and solution pond liner to allow leakage detection.
	° Construction of pregnant and barren solution ponds with synthetic double-liner systems with leak detection per RCRA guidance for hazardous waste.

Operational	° Use of alternative lixiviants (i.e., thiourea) to eliminate potential for cyanide contamination.
	° Installation of a system of ground-water monitoring wells.
Closure	° Flushing of heap with cyanicides (i.e., hypochlorite) to destroy residual cyanide.
	° Recontouring of heap and application of impermeable (i.e., compacted clay) cap.
Post-closure	° Long-term (i.e., 30-year) maintenance of heaps, monitoring of ground and surface waters, and maintenance of site security.

Many unknowns exist with regard to the type, quantity, and fate of cyanide in heap leached material. Only sparse data are available on the amount of cyanide in and around heap leach operations, especially after closure. Studies for the development of appropriate test methods (e.g., methods to determine representative data on cyanide content and speciation in heaps) and the collection of the needed data are just beginning. The preceding list of management practices presented was based on the assumption that controls may be required.

An attempt was made to develop a set of conceptual management practices defined on an example site basis. The practices are specified in sufficient detail to permit cost estimates. The diagrams presented describe both the construction and function of the management practices. Cost estimates are based on the assumed details of the management practices by using unit costs from sources such as the current edition of Means Construction Cost Handbook. Present-day costs in 1986 dollars are presented for direct-cost items (e.g., earth moving, compaction, and surveying) and indirect costs (e.g., engineering design, contingency, insurance, and bonds).

INCORPORATION OF FRENCH DRAINS IN LEACH PADS

The three main sources of potential cyanide release at gold/silver heap leach operations are the barren solution pond, the pregnant solution pond, and the ore heap. As discussed in Section 3, current industry practice includes the use of impermeable pads and liners in the construction of each of these three facilities. As insurance against potential cyanide releases, redundancies and overdesign of these liner systems may be appropriate in some cases. The need for such redundancies, however, must be determined on a site-specific basis.

In the design and construction of the leach pads, one management practice considered entails installation of a system of French drains beneath the leach pad. Pads are currently constructed of compacted clays, asphalt, or synthetic liners. Placement of a drainage blanket with leachate detection and collection capabilities between the subbase of native soils and the leach pad would allow the operator to determine if the integrity of the pads had been breached.

One active leach operation (at Pinson Mining Company near Winnemucca, Nevada) has installed a system of French drains beneath their leach pads. Individual leach pads at this site measure about 300 ft by 300 ft and are constructed of compacted clays and silts obtained from nearby borrow pits. Schematic diagrams of this system are shown in Figure 11. The drain systems beneath the leach pads are individually monitored to determine if any pads are leaking. Ultimately, as many as 60 contiguous pads with French drains may be constructed at this site. In this particular liner system, a layer consisting of 12 inches of free-draining gravel is placed between the clay leach pad and the compacted subbase. This drainage layer is sloped, as is the pad, at a 5 to 6 percent grade. Slotted, 2-inch, Schedule 40 PVC pipe is installed in the gravel along the two downgrade sides of the pad. Seepage through the pad would flow preferentially through the gravel along the surface of the compacted native soil subbase to the slotted collection pipes and then to a collection sump accessed by a manhole. The sump is periodically checked for the presence of seepage. If any seepage is found (none has been at this site), it can be pumped from the sump to the pregnant collection pond. If leakage is significant, the pad could be taken out of service and, if possible, repaired.

Another example is at Superior Mining Company's Stibnite Project, which is situated in a National Forest, near surface water, and over shallow ground water. This site incorporates a seepage collection drain pipe sandwiched in gravel between an upper liner constructed of 3-inch-thick asphalt and a lower liner of 30-mil PVC (Figure 12).[31] This perforated drain pipe collects any

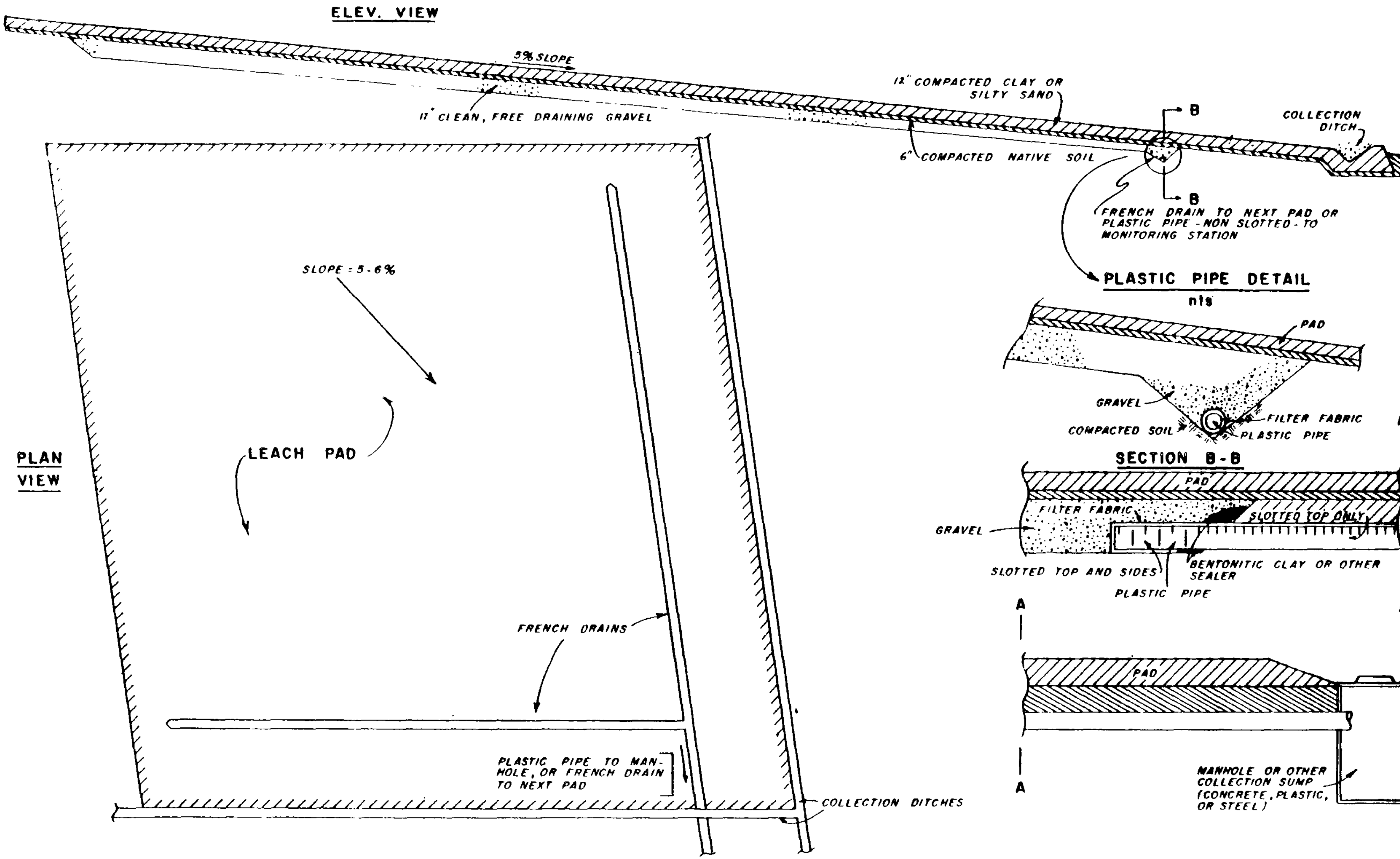


Figure 11. Specifications of French drains incorporated in the Pinson Mining Co. leach pads.

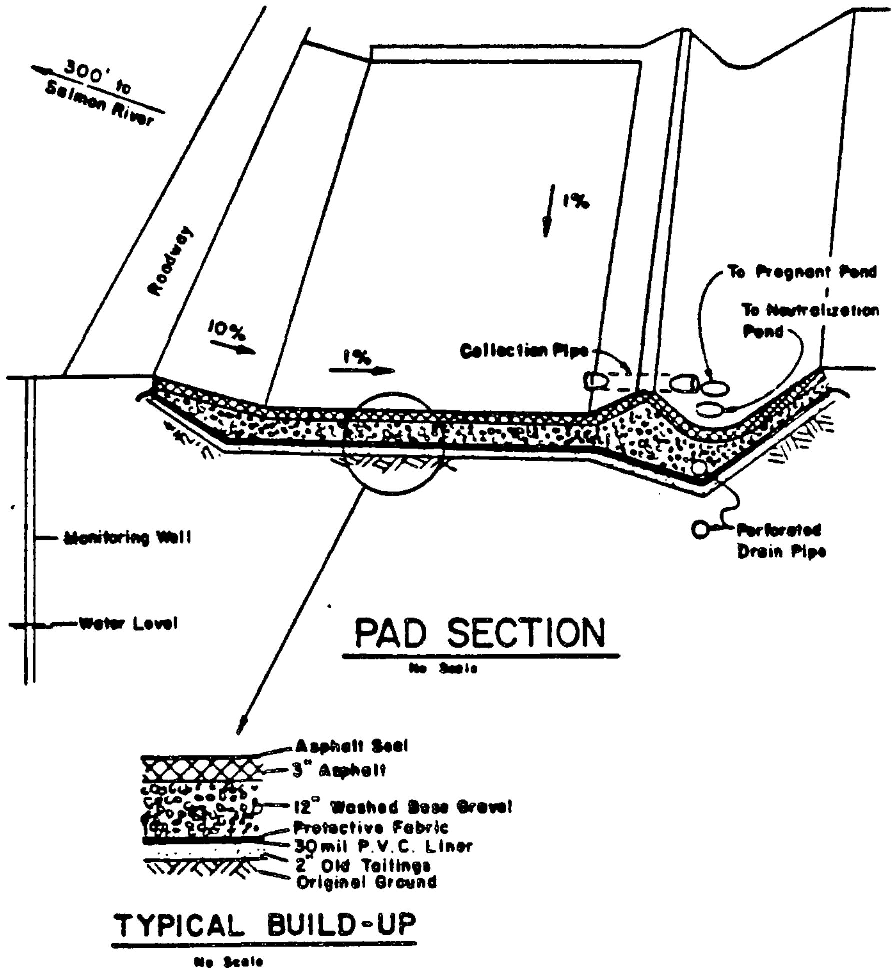


Figure 12. Design of leach pad leak detection system at the Superior Mining Co. Stibnite Operation.

Source: Ref. 31.

solution seeping through the asphalt layer and discharges it to the pregnant solution pond. A second drain pipe, placed 2 feet below this pipe and beneath the PVC liner, collects ground-water flow from beneath the pads and from adjacent hillsides. This flow is discharged outside the plant area. Both drains are sampled for free cyanide.

Without a system of drains (i.e., a leakage detection and collection system), ground-water monitoring or possibly the use of lysimeters beneath the pad would be the only way to determine leakage through the leach pad. Depending on the location of the monitoring wells and the hydrogeology of the site, considerable time could elapse before leakage is detected. By the time leakage is detected by ground-water monitoring, the ground water and native soils will already have been impacted. The use of French drains allows immediate detection of leakage through the pad. Such a system could be placed beneath liners constructed of clay, asphalt, or synthetic materials. The drain system would have to be constructed so that it could support the weight of the heap without failing and so that it would not compromise the integrity of the leach pad as a result of deflection or settlement of the drain blanket during the loading of the pad with ore (or afterwards). Such a system could only be placed during the construction of the pad; it could not be retrofitted to heaps during the operational phase. Many sites, however, conduct leaching on multiple pads that have been constructed at different times over the life of the operation. For example, French drains could be incorporated into new leach pads that are constructed at an existing site.

A conceptual system was considered for evaluation of a system incorporating French drains. Because of its proven design, a system such as that developed and implemented at the Pinson operation was chosen. The cost developed for the system was based on standard unit costs for each component. Preparing the cost estimates in this manner permits a comparison of the costs of a system with and without the French drains. The specific construction activities and estimated costs for these systems are shown in Table 5.

DOUBLE LINERS FOR PROCESS SOLUTION PONDS

As indicated in Section 3, the standard practice in the heap leach industry is the use of single synthetic liners in the pregnant and barren solution ponds. A layer of compacted clay is often placed beneath the

TABLE 5. COST OF CONSTRUCTING A CLAY LEACH PAD WITH AND WITHOUT A FRENCH DRAIN SYSTEM[a] (1986 dollars)

Cost item	Unit cost, \$/unit	Without French drain, \$	With French drain, \$
Direct costs			
Site preparation - clear and grub	0.29/yd^2	2,900	2,900
Remove and stockpile 6 in. of topsoil	1.45/yd^3	2,500	2,500
Remove 12-in. layer of soil	1.45/yd^3	-	5,000
Purchase and place 12 in. of gravel	16.16/yd^3	-	53,900
Install drain pipe	1.72/ft	-	930
Install 18-in. sump	23.05/ft	-	50
Level with a blade	0.44/yd^2	4,400	4,400
Compact base - three roller passes	51/h	410	410
Excavate and haul clay for 6-in. lift	7.81/yd^3	13,300	13,300
Place clay layer	1.34/yd^3	2,300	2,300
Add moisture and compact	1.21/yd^3	2,060	2,060
Construct 2nd and 3rd lifts		35,300	35,300
Subtotal direct costs		63,170	123,050
Indirect costs[b]		20,200	39,400
Total cost		83,400	162,000
Pad cost/ft^2		0.93	1.80

[a] Pad is 300 ft x 300 ft.

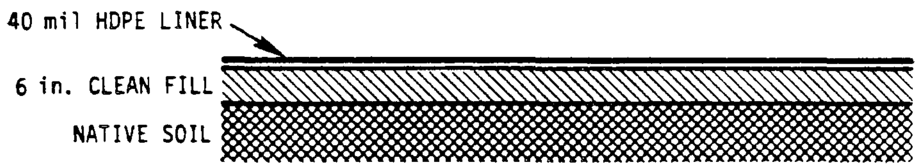
[b] Indirect costs are assumed to be 32 percent of direct costs.

synthetic liner, and some operations have constructed process ponds with double liners and leak detection. The process solutions themselves are a product, whereas EPA considers any solution seepage or leakage from the ponds to be a waste. Because release of leach solutions represents a loss of valuable product to the operator, the goal of no release is as important from a production standpoint as it is from an environmental viewpoint. The alkaline process solutions contain significant concentrations of free cyanide; therefore, the incorporation of some additional redundancies or overdesigns in the construction of these solution ponds may be warranted at some sites.

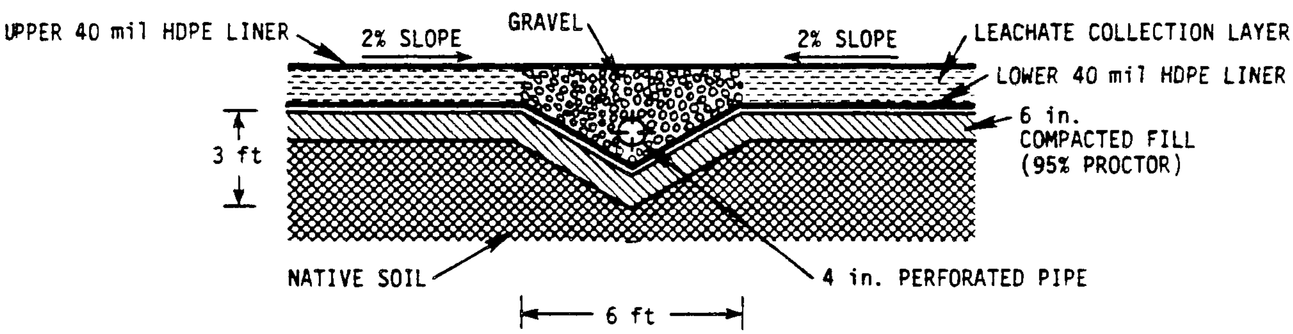
Although the standard practice is to use single liners, some sites already have double liners in their ponds (usually synthetic liners over compacted clay). The State of California considers the ponds at leaching operations to represent "threatening discharges" and therefore requires the use of double liners. This control, therefore, is both technologically feasible and a demonstrated practice.

A double-liner system that consists of two layers of 40-mil HDPE separated by a leachate detection and collection system was evaluated. In practice, the bottom liner may be constructed of native or modified clays, if sufficient quantities of suitable material exists on or near the site. The synthetic liners, however, were chosen to standardize the system. The use of synthetic liners also prevents the problems associated with assuring that a clay liner meets the permeability requirements (i.e., 10^{-7} cm/s) at the time of construction and over the life of the facility. A drainage blanket is placed between the liners; this can be a layer of free-draining sand or gravel or a synthetic drainage blanket. The latter was used in the evaluation. A leachate detection/collection system is installed in the bottom of the pond. This system of perforated pipes in the drainage blanket leads to a sump that can be accessed to determine if the upper liner has failed. If failure has occurred, the leachate can be removed from the sump. Details of the example liner systems are shown in Figures 13, 14, and 15.

Costs of the liner systems are detailed in Table 6. For the purpose of comparison, costs associated with a single-liner system (believed to be the industry standard) are also included. Dimensions of the pond are the same in both systems. The cost comparison indicates the double-liner system increases the cost of the pond by a factor of at least 2. The cost of constructing



SINGLE LINER SYSTEM



DOUBLE LINER SYSTEM SHOWING LEACHATE COLLECTION

Figure 13. Cross sections of single- and double-liner systems used to develop cost estimates.

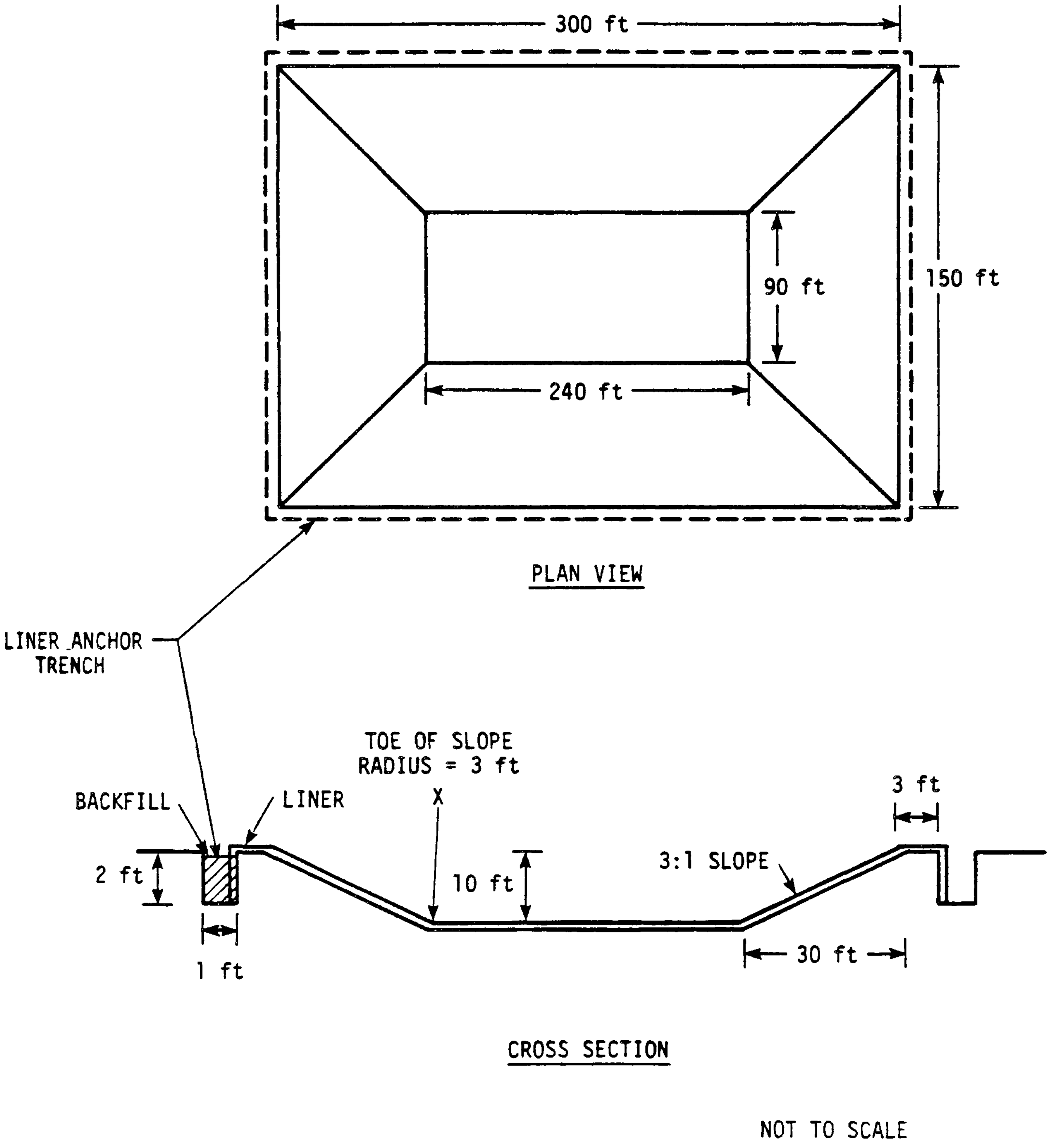


Figure 14. Design of process solution pond with single 40-mil HDPE liner used for cost estimating.

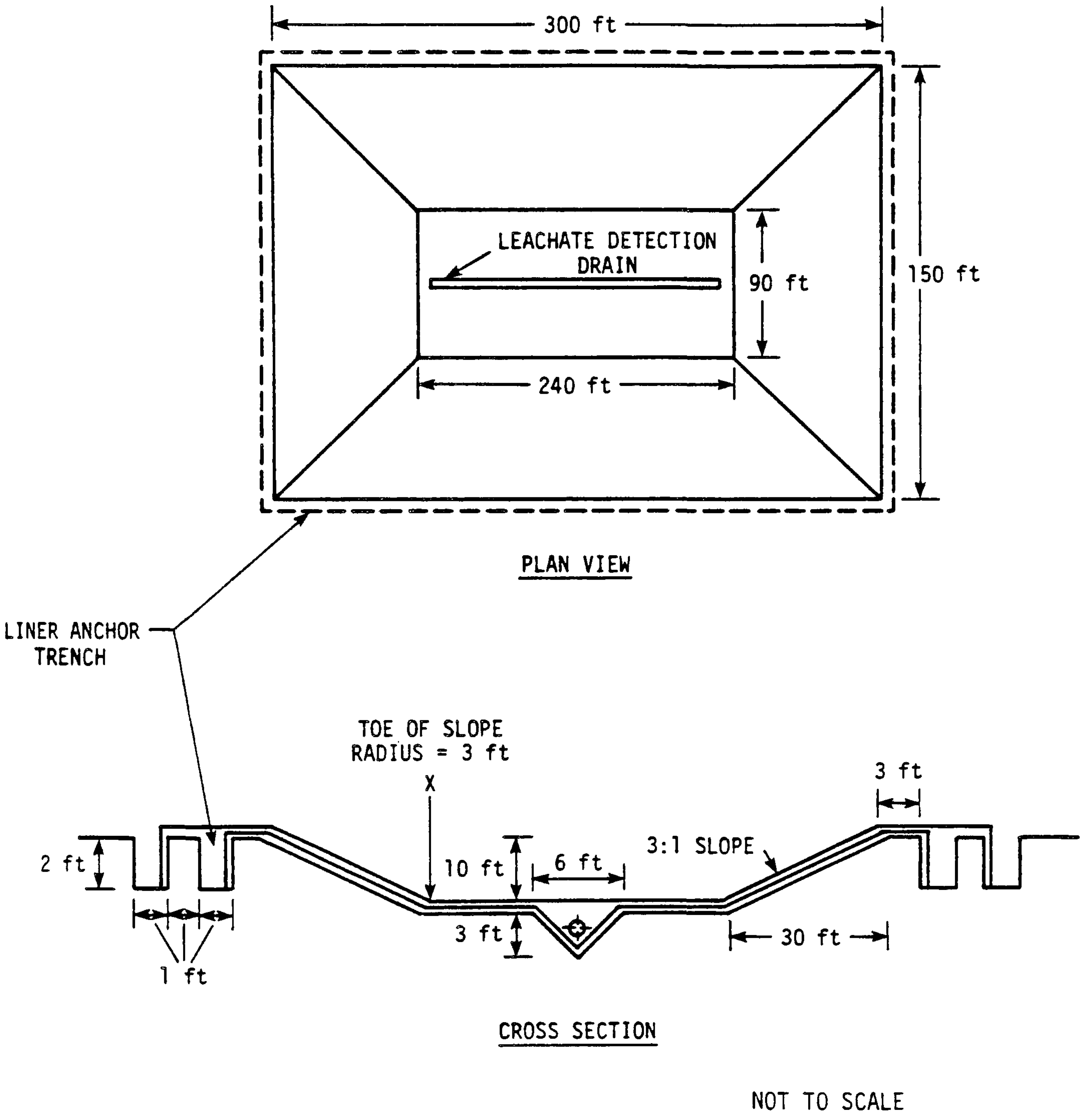


Figure 15. Design of process solution pond with double 40-mil HDPE liner system leak detection used for cost estimating.

TABLE 6. COMPARISON OF COSTS OF PROCESS SOLUTION PONDS CONSTRUCTED WITH SINGLE AND DOUBLE LINERS (1986 dollars)

Cost item	Unit cost, \$/unit	Single liner system, \$	Double liner system, \$
Direct costs			
Pond excavation	$0.97/yd^3$	12,600	12,600
Anchor trench excavation	$2.99/yd^3$	210	420
Backfill of anchor trench	$0.96/yd^3$	70	130
Drain excavation	$2.99/yd^3$	-	240
Placement of 6-in clay bed	$1.17/yd^3$	1,060	1,080
Primary liner (40-mil HDPE)	$0.55/ft^2$	28,300	28,600
Secondary liner (40-mil HDPE)	$0.55/ft^2$	-	29,300
Drainage blanket (HDPE)	$0.25/ft^2$	-	12,300
2-in. Schedule 40 slotted drain	1.72/ft	-	410
Sump and 2-in. connector	-	-	460
Gravel backfill for drain	$9.31/yd^3$	-	480
Subtotal direct costs		42,200	86,000
Indirect costs[a]		13,500	27,500
Total cost		55,700	113,500

[a] Indirect costs are estimated to be 32 percent of direct cost. Indirect costs include engineering, design, and contingencies.

the pregnant and barren solution ponds at a site can represent a significant percentage of the total capital cost of the operation. The impact of a double-liner requirement on the viability or profitability of heap leaching has to be determined on a site-by-site basis. The additional cost of double liners will definitely increase the cost to produce each ounce of gold. The amount of such increase depends on processing rates, recovery efficiencies, ore grade, and other site-specific parameters.

ALTERNATIVE LIXIVIANTS

Cyanide is the only lixiviant currently used at commercial precious metal heap leach operations. Because of the actual or assumed environmental problems associated with cyanide, the question of the availability of suitable substitutes for cyanide is raised. The development of alternative lixiviants that could replace cyanide in heap leach operations is still in the laboratory or pilot-scale testing stage. Pilot tests of some alternative lixiviants reportedly have been performed with some success in Australia, New Zealand, South Africa, Taiwan, and the U.S.S.R.[32] Publications were found concerning the use of ammoniacal thiosulfate,[33] malononitrile,[34] and thiourea[35,36] as alternatives to cyanidation; however, these alternatives are experimental and require additional developmental research on a commercial scale before they realistically could be considered. Thiourea, which has received the most attention and serious examination, is discussed in more detail in the following paragraphs.

Thiourea $[CS(NH)_2]_2$ is an organic compound derived from urea. Thiourea crystals dissolve in water to yield an aqueous form that is stable in acidic solutions.[32] In aqueous solution, it reacts with certain transition metal ions to form stable cationic complexes.[32] Extraction of gold by thiourea requires that the pH of the leach solution range between 0.5 and 2.0, as opposed to the alkaline pH (9 to 11) necessary for cyanide leaching. Experimental results indicate that the leaching ability of thiourea is significantly reduced at a pH above 2.0. Sulfuric or nitric acids can be used to acidify the leach solution. The thiourea reaction with gold also requires the presence of a condensed-phase oxidant, usually a ferric iron compound. In cyanide leaching, the oxidant is gaseous atmospheric oxygen. The dissolution reactions for thiourea and cyanide leaching are as follows:[37]

0.5 - 2 pH

Cyanide: $2Au + 4NaCN + \frac{1}{2}O_2 + H_2O \rightarrow 2Na[Au(CN)_2^-] + 2NaOH$ (Eq. 3)

Thiourea: $2Au + 4TU + Fe_2(SO_4)_3 \rightarrow [Au(TU)_2^+]_2\ SO_4 + 2FeSO_4$ (Eq. 4)

$2Ag + 6TU + Fe_2(SO_4)_3 \rightarrow [Ag(TU)_3^+]_2\ SO_4 + 2FeSO_4$ (Eq. 5)

The effectiveness of thiourea leaching is controlled by the amount of thiourea in solution, the leaching time, and the amount of trivalent iron (Fe^{+3}) present. One of the main advantages of thiourea is that it can leach gold from ore in a matter of hours instead of the days required for leaching with cyanide. Another advantage is that thiourea does not form complexes with cations present in the gangue mineralogy as readily as does cyanide.[32]

One major problem with thiourea leaching is that the reagent cost is approximately 25 percent more than with cyanide leaching.[10] Another problem is the amount of reagent consumption through oxidation; oxidation must be controlled to prevent excessive reagent consumption. Also, the intermediate product of oxidation of thiourea is formamidine disulfide, which can coat the ore particles and prevent fresh thiourea from reacting with the available gold. The addition of sulfur dioxide gas can control the oxidation and restore thiourea at the expense of formamidine disulfide.[37] Still another potential problem is that thiourea leaching requires a very acidic environment; therefore, the heap may have to be neutralized during closure. Native sulfur that is produced from the decomposition of thiourea and left in the leach residue could create acidic leachate during precipitation events, which, in turn, could mobilize metals in the post closure period.

As an example of a conceptual application of thiourea leaching, NERCO Minerals estimated that for every ton of ore treated at its Candelaria Mine, 178 lb of H_2SO_4 and 8 lb of H_2NO_3 would be required to achieve the acidic pH necessary to use thiourea as the lixiviant. (Current cyanidation leaching consumes 2.5 pounds each of sodium cyanide and lime per ton of ore.) They further estimate that the cost of thiourea reagent alone at the Candelaria operation (a silver heap leach operation) would be \$53 per ounce of silver recovered. Based on current silver prices of about \$5 per ounce, thiourea obviously is not a viable option at this site.

Pyper published results from experiments performed on comparisons of thiourea and cyanide leaching.[36] Variables in the experiments were pH, temperature, time, and the concentrations of thiourea and ferric iron. The ore treated was a classic Carlin-type ore (a dolomite siltstone in a quartz matrix with finely disseminated gold) obtained from the Northumberland mining area in south-central Nevada.[36] The results of these experiments indicate that thiourea can leach gold from this type of ore with similar or better yields than cyanide, but at higher cost (no exact amount was stated). Optimum leaching was obtained when 1) temperature was 20° to 25°C, 2) thiourea concentration was 50 to 100 kg/ton, 3) ferric sulfate was 5 kg/ton, 4) leaching time was 8 to 24 hours, and 5) pH was 1.0.

Thiourea eventually may become an alternative commercial-scale lixiviant for some applications in precious metals heap leaching if oxidation of the thiourea can be controlled to reduce reagent consumption and if the cost of reagents can be reduced. Sulfur dioxide may be a suitable treatment for preventing the oxidation of thiourea. Thiourea rapidly leaches gold from ore in pilot and bench tests; this speed of leaching may help to offset the difference in cost between cyanide and thiourea leaching in some situations. However, the technology of recovery of precious metals from thiourea complexes is not well developed. The majority of gold ores in the United States contain carbonates that would require that prohibitive amounts of acid be used. Before commercial scale applications are made, several environmental concerns related to thiourea must be addressed fully. For example, extremely acidic solutions may require additional or different composition liners; the need for post-leach neutralization must be addressed; the toxicity and mobility of Thiourea and its degradation products (e.g., formadine disulfide) must be evaluated; and the possibility of acid formation within the heap after closure with subsequent mobilization of metals must be studied.

LEACHATE DETECTION

As indicated earlier, gold heap leaching operations incorporate three primary operational units that may have a direct environmental impact on surrounding soils, geology, and ground-water quality: the barren solution pond, the heap leaching pad and associated solution collection systems, and the pregnant solution pond. The primary constituents of concern are cyanide and metals associated with the leach ore. Although each operation has unique process characteristics and design features, all operations also have several common design features, which include synthetic liners in the barren solution pond, low-permeability heap leaching pad liners and solution collection systems, and synthetic liners in the pregnant-solution pond. The primary purposes of these design features are to manage solution losses and fluid balances as an integral part of the operation and to reduce the potential for soil and ground-water contamination.

In addition to operational management practices, corrective actions may have to be implemented to control prior releases or newly discovered releases of contaminants into the surrounding environment. Corrective actions may be required at any point in the operational or closure phase of a facility life. The monitoring of soil and ground water is often fundamental to determining the need for the implementation and establishment of the design features of such corrective actions.

Our evaluation of gold heap leaching operations uncovered little information on recently implemented facility-specific monitoring systems or corrective actions. Therefore, data are sparse on how effective current operational techniques are in preventing uncontrolled releases or in protecting the environment. However, some form of leachate detection currently is practiced at many sites. For example, the State of Nevada requires that observation ports be installed beneath the liners of solution ponds to allow rapid detection of liner failure. Similarly, the State of California requires monitoring of groundwater and the vadose zone. Little data were found on monitoring systems or corrective actions applied specifically to gold heap leaching operations. Consequently, several conditions relative to monitoring system design and corrective actions must be assumed. These assumptions are reflected in the following discussion on ground-water monitoring.

A key assumption concerns the meteorological and hydrogeological setting in which the majority of heap operations are located, i.e., an arid environment with deep ground-water tables. Costs also must be considered in the planning and design of a ground-water monitoring system and any necessary corrective actions. Because no actual cost data were available on the design and implementation of monitoring systems at gold heap leaching facilities, it was necessary to rely on data obtained from ground-water monitoring systems installed at land disposal facilities for the development of cost information. In the evaluation of these cost data, a range was developed (whenever possible) to reflect the effects of gold heap leaching operations and typical environmental and hydrogeologic setting on a ground-water monitoring program.

The effective implementation of any ground-water monitoring program requires a fundamental understanding of the surrounding geology and hydrogeology and the operational characteristics of the gold heap leaching facility. The purpose of the monitoring system is to detect and assess leachate production resulting from the gold heap operation (barren solution pond, heap pad, and pregnant solution pond) and to characterize the pathways for contaminant transport.

Information on the geologic and hydrogeologic setting of the gold leaching operation should be evaluated on both a regional and site-specific scale. The data should include:

- Nature, history, and location of the leaching operation
- Characteristics of the ore and deposition practices
- Size and location of the solution ponds and leach pads
- Design features of the solution ponds and leach pads
- Current surface- and ground-water characteristics and uses in proximity to the facility

Historical precipitation records and any existing geologic and topographic maps also should be compiled.

Data on the materials used in the gold leaching operation help in the identification of the characteristics of potential contaminants and their likely routes of migration. The primary constituent of concern is cyanide; however, heavy metals present in the ore also may be a concern. The potential for release of these constituents is a function of the effectiveness of the pad collection system and liners to contain and collect the process solutions. The extent to which these constituents migrate in the surrounding soils and geologic units depends on the composition of the soils and the structural features of the bedrock. Because most gold heap leaching operations are located in the arid West, the depth to ground water may be significant, and the effects on the hydrogeologic system may take several years to detect. Also, the high evapotranspiration rates may retard the downward transport of released contaminants and cause them to be confined primarily to the vadose zone. Detection monitoring in the vadose zone is an emerging science, and is often difficult and expensive to implement and maintain.

Monitoring wells are generally used to obtain site-specific data on the geologic and hydrologic characteristics of the site and to detect contaminants that may have been released to the subsurface environment. Because data were obtained on gold heap leaching operations that have actually installed ground-water monitoring networks around their process units, little perspective exists to assist in establishing a proven design for a generic monitoring system. In the establishment of monitoring well locations and screen depths, however, consideration should be given to identifying background water quality, transport pathways, environmentally sensitive areas, local and regional receptors, and the water-bearing zones to monitor. The approximate number and location of monitoring wells will depend on the number and complexity of the gold heap leaching process units, their size, the characteristics of the surrounding surface, and the subsurface environment.

A typical monitoring network consists of a series of nonpumping wells located downgradient from the solution ponds and heap leaching pad. In addition, at least one well is located upgradient in an area that has not been affected by potential contaminant migration. The number and the complexity of the well network is purely a site-specific determination. Figure 16 shows an example system for a small operation. Water quality studies around similar ore-processing operations have entailed the use of both new and existing wells. These networks have included existing water supply wells, multidepth well nests, and single large-diameter monitoring wells.

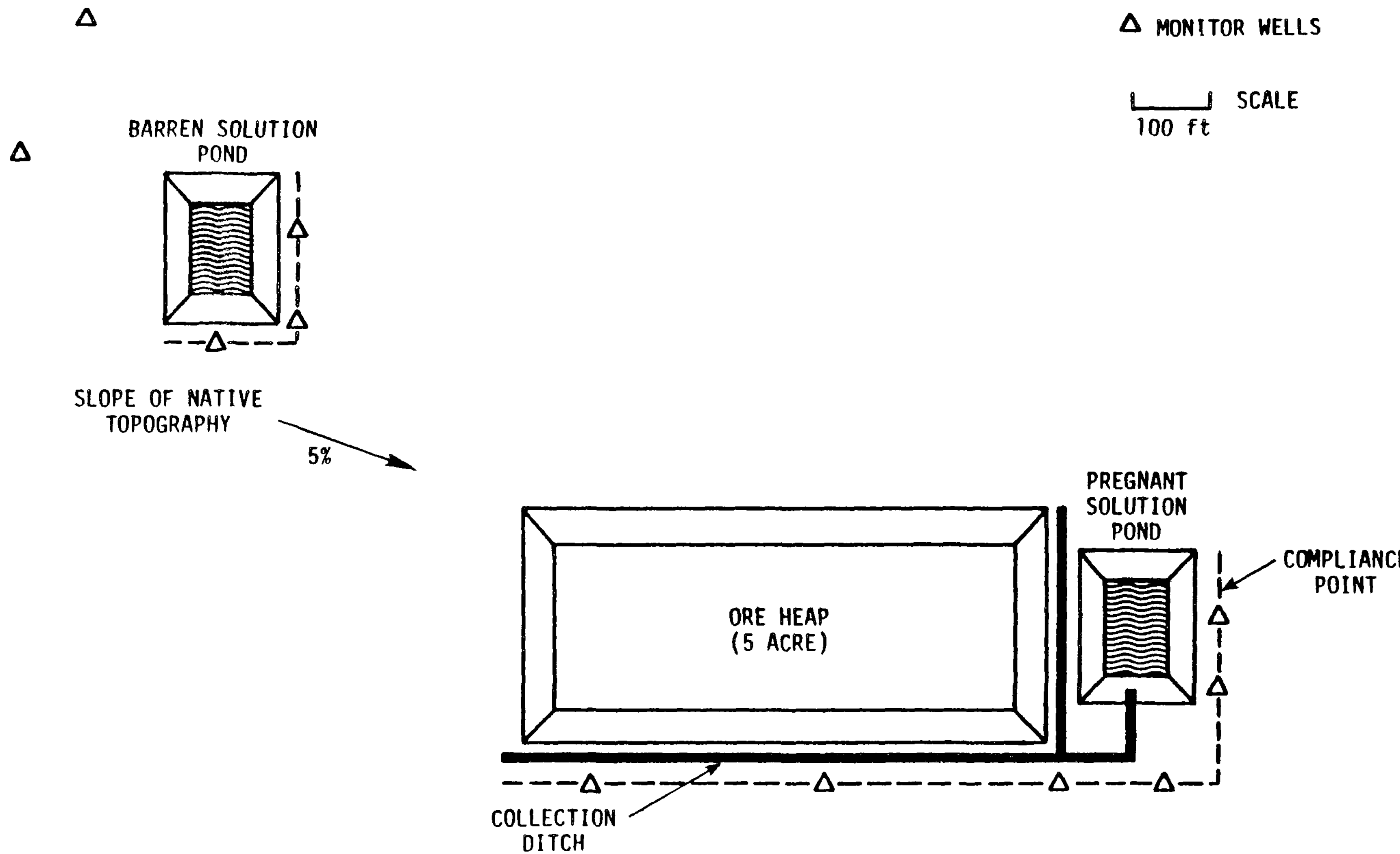


Figure 16. Conceptual application of a detection monitoring system at a small heap leach operation.

A ground-water monitoring program will initially be designed to detect contamination. If ground-water contamination is detected, additional wells may then be installed to define dispersion and attenuation of the contaminants. If improperly pursued, this process can be expensive and time-consuming; therefore, such a program should be balanced against the potential health and environmental impacts of gold heap leaching operations.

The depth of monitoring wells depends on the depth and characteristics of the underlying aquifer and the vertical spread of potential contaminants. At gold heap leaching operations, the depth of wells probably will vary considerably (e.g., from 25 to 300 ft.); however, in the arid regions of the southwest, such wells are frequently deep.

Sizing of monitoring wells will be a function of the flow rates and depth of the aquifer and proposed sampling methods. Well diameters may vary from 2 inches to 6 inches. The most common well is 4 inches in diameter and placed in a 6- to 8-inch annulus. Drilling methods are determined on the basis of the geologic formation to be penetrated, the depth and size of the hole, and the potential for contamination as a result of the drilling itself. Methods and materials used during well construction should not interfere with ground-water quality. Methods outlining well construction and materials application are provided in EPA's "Draft RCRA Ground-Water Monitoring Technical Enforcement Guidance Document."

The cost for installing a monitoring well system at a gold heap leaching operation will vary greatly from site to site. The primary factors that influence costs are the size of the operation and the complexity of the local hydrology. The characteristics of the ground water, the extent of contamination, the availability of supplies and equipment, and local wage rates will also affect the cost.

Installation costs include the costs of drilling, well materials, crews, and equipment, all of which will be affected by the conditions under which the well system must be installed. The principal factors are the diameter, depth, and components of the well; the drilling specifications; the geologic material; the sampling requirements; and site access. Table 7 presents some typical unit costs for drilling and installing well systems.

TABLE 7. 1986 COSTS FOR DRILLING AND INSTALLING 2- TO 4-INCH DIAMETER WELLS[a,b]

Drilling method	Cost, $/ft
Conventional hydraulic rotary	24 to 39
Reverse circulation hydraulic rotors	34 to 44
Air rotary	17 to 24
Auger (hollow-stem)	11 to 21
Bucket auger	10 to 20
Cable tool	15 to 17
Hole puncher (jetting)[c]	39
Self-jetting[c]	21
Mobilization	488 to 586/rig

[a] Source: U.S. Environmental Protection Agency. Remedial Action at Waste Disposal Sites (revised). EPA 625/6-85-006, 1985 (modified).

[b] Includes drilling, well material, and installation costs.

[c] Includes rental of all necessary equipment, e.g., well points, pumps, and headers.

Based on the example site shown in Figure 16, an assumed cost of $50 per foot for well installation, and our best engineering judgment, the cost of installing a system of 10 to 13 wells to depths of 25 to 300 feet is estimated to be $12,500 to $195,000. Consultant fees for a qualified hydrogeologist could be expected to range from $6,000 to $50,000. Analytical costs (assuming $150 per sample, semiannual sampling, and quadruplicate samples) would amount to about $12,000 to $16,000 plus the cost of reporting and recordkeeping. These costs point up the great variability due to site-specific conditions. The number of wells required and sampling and analytical costs will vary significantly from site to site. As pointed out earlier, if this detection monitoring were to indicate the presence of contamination, assessment monitoring probably would be required, and installation of such a system would entail significant additional costs.

CYANIDE DESTRUCTION

During the closure and post-closure periods, the heap leach residue is the only potential source of cyanide contamination. Current permitting requirements state that process solutions present in the barren and pregnant solution ponds must be evaporated to dryness, or be treated to destroy cyanide and then released if evaporation is not possible. The current practice at most sites is to rinse leach residue with fresh water. The fresh water rinse is applied with the same distribution system used during leaching. Application rates are also the same (e.g., 0.005 gpm/ft^2). The rinse time may be predetermined, as would be the case when leach residue is removed from reusable pads, or it may continue until some preset cyanide concentration (e.g., 0.2 mg/liter) or pH (e.g., pH 8.5) in the leachate is achieved. Rinsing typically lasts from 1 day to a week or more; however, no published information is available on the effectiveness of this practice.

As indicated earlier, very few data are available on the concentration and fate of cyanide in heap leach residue. The need for post-leaching cyanide destruction must be assessed on a site-specific basis. For example, cyanide destruction has been incorporated into the post-leaching operation of the Superior Mining Company operation described later in this section.

One of the control options evaluated during this study is the addition of a cyanicide, a strong oxidant, to the rinse solution at the time of closure. The addition of a cyanicide would help to control the amount of free cyanide left in the leach residue that could escape to the environment. However, some stable cyanides such as the iron complexes may not be destroyed. A variety of processes have been demonstrated to be effective in destroying cyanide or in removing it from the solution. These treatments include natural degradation, evaporation, alkaline chlorination, oxidation with sulfur dioxide air, biodegradation, oxidation with hydrogen peroxide, adsorption on ferrous sulfide, acidification-volatilization, ozonation, ion exchange, chemical precipitation, electrochemistry, reverse osmosis, ion flotation, adsorption on activated carton, electrodialysis, high-pressure oxidation, photolysis, and polymerization.[38] Some of these methods are applicable to the treatment of cyanide-containing solutions from conventional cyanidation processes, and some may be effective in destroying residual cyanide contained in heap-leached material.

The form of the cyanide present in heap leach residue depends on the mineralogy of the ore. The most likely types of cyanide species are listed in Table 8 in the order of increasing stability. The stabilities of the compounds are important in determining an effective treatment and the quantity of reagent required. Leach residue probably will also contain significant quantities of thiocyanate, which requires an additional amount of reagent in most oxidation-type cyanide destruction reactions.[38]

TABLE 8. CYANIDE COMPLEXES LIKELY TO BE PRESENT IN LEACH RESIDUE[a]

Terms	Forms of cyanide
1. Free cyanide	CN^-, HCN
2. Simple compounds	
a) Readily soluble	NaCN, KCN, $Ca(CN)_2$, $Hg(CN)_2$
b) Relatively insoluble	$Zn(CN)_2$, $Cd(CN)_2$, CuCN, $Ni(CN)_2$, AgCN
3. Weak complexes	$Zn(CN)_4^{2-}$, $Cd(CN)_3^-$, $Cd(CN)_4^{2-}$
4. Moderately strong complexes	$Cu(CN)_2^-$, $Cu(CN)_3^{2-}$, $Ni(CN)_4^{2-}$, $Ag(CN)_2^-$
5. Strong complexes	$Fe(CN)_6^{4-}$, $Co(CN)_6^{4-}$

[a] Source: Reference 38.

Natural degradation, evaporation, and alkaline chlorination are the cyanide reduction and destruction processes that have been associated with heap leach residue. Natural degradation and evaporation are the most common methods of destroying any cyanide left in the residue after removal of solution from leach residue following the water rinse. Natural degradation of cyanide results from a combination of physical, chemical, and biological processes. These processes include volatilization, photodecomposition, chemical oxidation, microbial oxidation, chemical precipitation, hydrolysis, and adsorption on solids.[38] Volatilization is the most important process. When exposed to air, HCN vaporizes from cyanide solutions, especially if the pH is below 10.5.[39] As the pH of entrained solution falls from operating levels, cyanide volatilization occurs.[39] The effectiveness of natural degradation depends on the species of cyanide present, pH, temperature (which affects reaction kinetics), bacterial metabolism, photodegradation, and aeration.[38] If sufficient time is allowed, natural processes will return heap leach material to acceptable conditions.

Because most heap leach operations are located in arid regions (e.g., the ratio of evaporation to precipitation can be as high as 10 to 1), evaporation plays a major role both in removing solution from the heap and in determining if any leachate will be formed.

The alkaline chlorination process for cyanide destruction is a proven technology, and it is the most highly developed of all available methods in terms of experience, simplicity, control, availability of equipment, and engineering expertise. This process destroys most cyanides except iron cyanide and the more stable metallo-cyanide complexes, which may be the most prevalent forms in leach residue. Calcium hypochlorite, sodium hypochlorite, or chlorine gas, plus lime or caustic to maintain an alkaline pH can be used in solution to treat heap leach residue. The oxidation of cyanide by calcium hypochlorite occurs in two stages:

$$2NaCN + Ca(OCl)_2 + 2H_2O \rightarrow 2CNCl + Ca(OH)_2 + 2NaOH \qquad \text{(Eq. 6)}$$

$$CNCl + 2NaOH \rightarrow NaCNO + NaCl + H_2O \qquad \text{(Eq. 7)}$$

Chlorine is consumed by other oxidizable substances present in the leach residue. A dramatic increase in reagent usage will occur if thiocyanate is present, as is usually the case.[38]

As indicated in the preceding equations, a significant quantity of chloride results from the destruction of cyanide. Chloride is soluble, highly mobile in the environment, and is conservative; that is, it is not attenuated or degraded. The potential therefore exists for chloride contamination in groundwater or surface water as a result of efforts to destroy cyanide.

Three references found in the literature document the content and fate of cyanide in heap leach residue and the effectiveness of treatment with chlorine. Englehardt reported on the natural degradation of cyanide in an inactive leach heap at an Anaconda operation at Darwin.[23] At this facility, 84,000 tons of agglomerated tailings were leached in heaps stacked 15 ft high. During the 6 months of operation, about 105,000 pounds of NaCN was applied to the heaps.[23] About 70 percent of the NaCN applied was consumed during leaching by the cyanicides in the ore. Most of the cyanide remaining was removed by the fresh-water rinse during the post operations. About 12,000 pounds of NaCN remained in the entrained solution in the leached tailings.

Almost all of the cyanide was present as free cyanides. Over the course of the 15-month study, the moisture content in the heap decreased from 14.4 to 13.1 percent.[23] The water-soluble residual cyanide content decreased from 0.58 gram/liter to 0.11 gram/liter.[23] The decrease in cyanide was due to natural degradation, as no treatments were applied during this period.

As an alternative, treatment of the leach residue with alkaline chlorine was tested.[23] Pilot-plant tests indicated that treating the leach residue with a calcium hypochlorite solution (0.5 gram/liter) immediately after leaching was effective in destroying the cyanide left in the heap. Consumption of the hypochlorite was 0.6 pound per ton of leach residue.[23] This treatment was reported to be quick and effective, but it would be expensive in terms of reagents and manpower.[23]

Another reference to hypochlorite treatment of heap leach residue concerns the Annie Creek operation in South Dakota.[21] At this site, a hypochlorite solution was flushed through heap leach residue, and then fresh water was recirculated through the system. In one month, the cyanide concentration in the solution had decreased from 300 to 3.4 ppm.[21] A year later the cyanide content ranged from 0.2 to 0.01 ppm.[21] The reported information, however, does not include data on hypochlorite dosage or consumption, on recirculation rates, or on the original concentration and speciation of cyanide present in the residue.

Superior Mining Company has operated a heap leach operation incorporating post-leach cyanide destruction using hypochlorite.[31] The operating permit issued by the U.S. Forest Service requires cyanide destruction and a

24-hour average free cyanide concentration not exceeding 0.2 mg/liter in the rinse solution leaving the heap; no single sample can exceed 1.0 mg/liter. To meet this limit, Superior treats the leach residue with an alkaline chlorine/calcium hypochlorite solution that is prepared on site. At this site, newly mined ore is crushed to -1.25 inches and treated with lime (1.5 to 2 pounds/ton) before it is stacked on the five leach pads. The heaps are leached with alkaline cyanide solution for 20 days and then treated for cyanide destruction for 6 days before being offloaded to a spoil disposal area on site. The chlorine concentration of the treatment solution is about 1000 ppm free chlorine. Chlorine is consumed at the rate of 4000 pounds per day, and 8000 pounds of lime per day is required to maintain the high pH that is necessary.[31] After treatment with chlorine, the leach residue is excavated and hauled to the disposal site where it is spread out in layers 1 to 2 feet thick. This allows further oxidation and volatilization of any remaining cyanide and chlorine. No significant accumulation of chloride or heavy metal salts has been detected.[31] No information was given on cyanide concentrations or accumulation in leach spoil prior to treatment.

When this system is used, the facility must incorporate at least one additional pond (a neutralization pond) in its solution management system (Figure 17). This neutralization pond receives the solution that percolates through a heap during the post-leaching neutralization/cyanide destruction process. Existing pregnant and barren solution ponds cannot be used for this purpose because they are needed to manage leach solutions being applied to the active heaps. The same distribution system that is used during leaching, however, can be used to spray the chlorine solution over the heap. The system at the Stibnite mine also incorporates a 30-ton lime bin and an auger feeder to an 8 ft by 8 ft mixing tank having a 15-hp agitator, which produces the milk of lime (Figure 18). The milk of lime is injected into the pipe carrying solution from the chlorine pond by means of a venturi injector. Chlorine gas, regulated by a chlorinator, is then injected into this line by using another venturi injector. Chlorine gas is supplied by ten 1-ton chlorine cylinders.

An evaluation was made of the cost of installing and operating an alkaline chlorination system for cyanide destruction during the post-leaching rinse. The evaluation assumed a system with the specifications of that operated at the Stibnite facility. The cost of this system, estimated for a

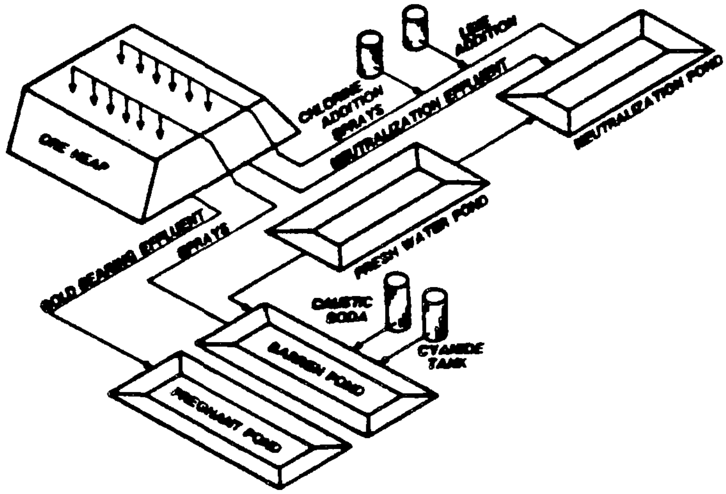


Figure 17 . Example site layout showing additional pond required for cyanide destruction/neutralization.

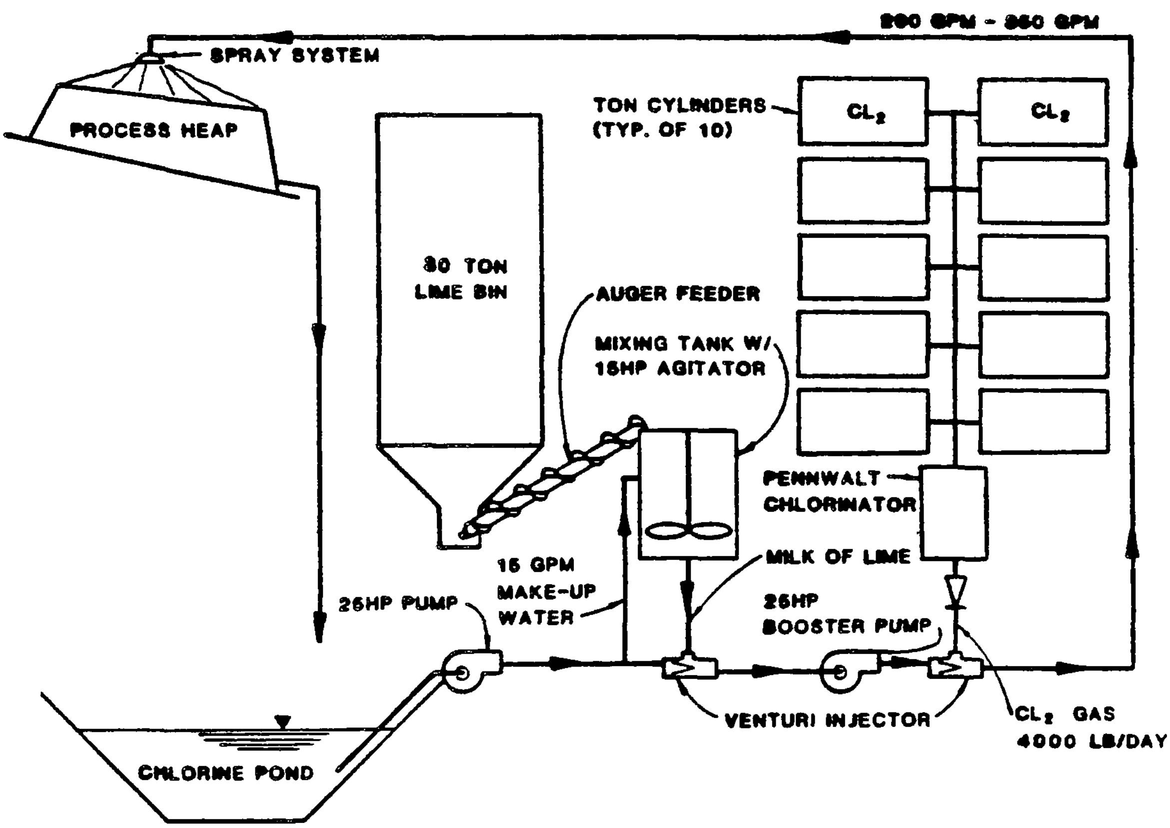


Figure 18. Example process flow diagram of cyanide destruction circuit.

Source: Ref. 31.

range of processing rates, is shown in Figure 19. The system specified is sized to produce 200 to 350 gpm of alkaline chlorine solution, a volume sufficient for application over 0.9 to 1.6 acres at a rate of 0.005 gpm/ft^2. Heaps with much larger surface areas and solution flow rates are common. To treat a large heap (e.g., one with 20 acres of top surface) would require that the capacity of the example alkaline chlorination system be increased by a factor of 20 to allow treatment of the entire heap at one time. As an alternative, a smaller system could be used to apply the treatment solution at a slower rate for a longer time or at the same rate in sequential applications over small portions of the heap.

In the case of multiple-use pads, a system such as that used at Stibnite would be in constant use over the life of the operation. At sites using single-use pads, however, such a system may only be applicable at closure. In addition, at operations having single-use pads, the leach residue would not be excavated and spread out so that additional oxidation of cyanide and chlorine could take place. If cyanide destruction occurs only at closure, the existing process solution ponds, distribution system, and lime-addition facilities could be used. In this case, only the capability of adding chlorine would have to be provided.

All of the essential elements of the solution-handling system necessary to effect cyanide destruction by alkaline chlorination of heap leach residue during closure are already present at each operation. Solution storage reservoirs, pumps, distribution pipes, and lime addition equipment used during leaching operations could also be used during alkaline chlorination. Calcium hypochlorite would just replace cyanide in the flow scheme. Thus, the cost of this treatment represents the cost of the reagents and the manpower to operate the system.

CAPPING

The application of a clay or synthetic cap over a waste disposal unit is required in the closure of hazardous waste facilities. The purpose of this cap is to prohibit infiltration of rainfall or surface water run-on and thereby to preclude formation of leachate. During the post-closure period at heap leach operations, only the leach residue remains as a potential source of cyanide contamination through leachate generation. Capping this residue

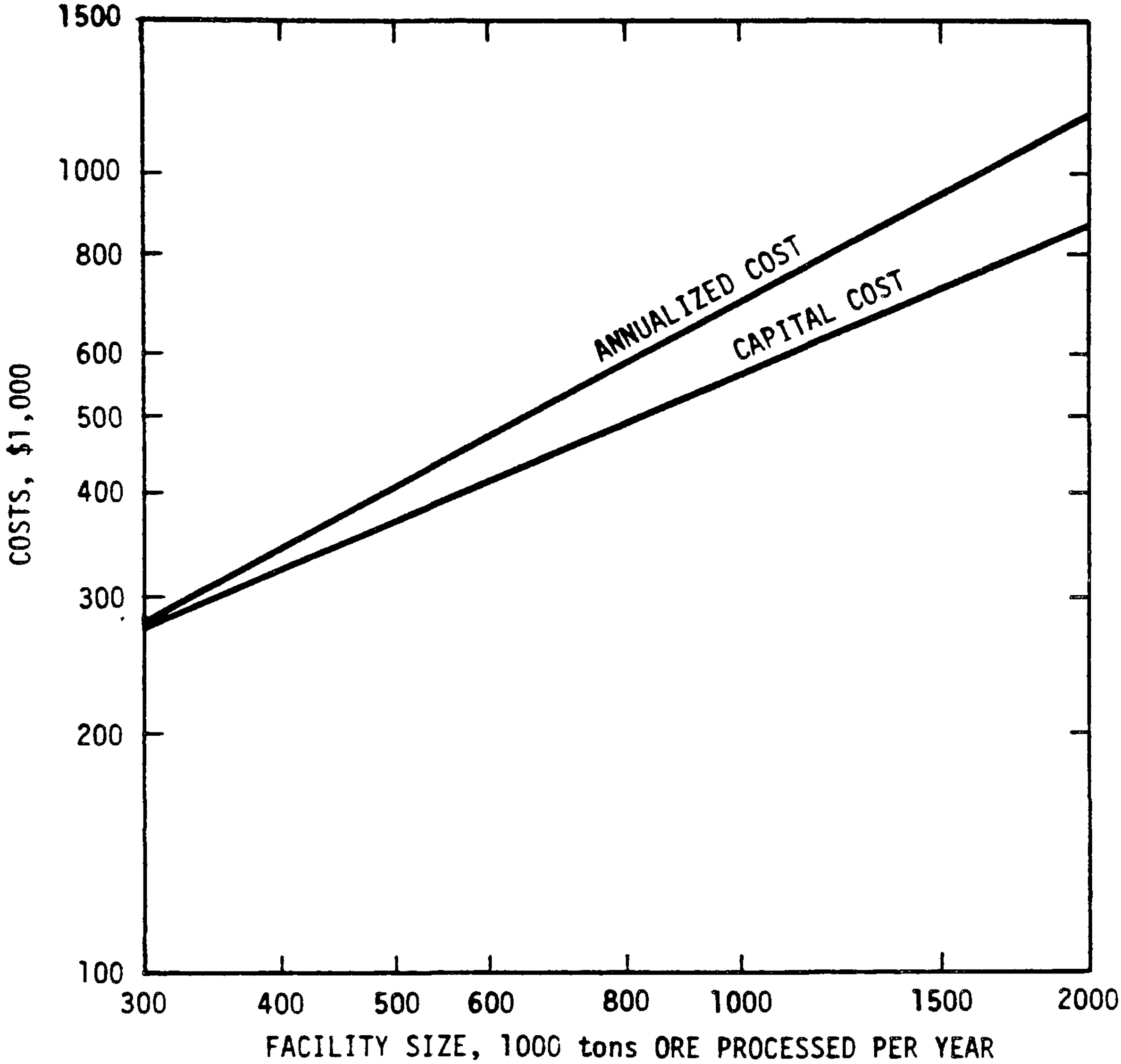


Figure 19. Capital and annualized costs of cyanide neutralization system at a gold leaching facility.

pile could reduce this potential. As indicated earlier in this report, however, the actual need for such control has not been documented because little is known regarding the content and fate of cyanide in leach residue. Also, capping would hinder the natural degradation of cyanide remaining in leach residue by limiting volatilization.

Cyanides remaining in the leach residue could degrade to mobile forms over time; however, the leachate formation potential is low at many sites. For example, at the Darwin operation in Southern California, evaporation (approximately 70 inches/yr) greatly exceeds precipitation (3 to 7 inches/yr). Leachate formation potential is also low in the individual heaps at the Pinson Mining operation, which typically retain about 250,000 gallons of solution before their field capacity is reached. The approximate surface area of the top of each of these heaps is about 114,000 ft^2. For a heap to reach field capacity and start producing leachate as a result of a precipitation event in the post-closure period would require that more than 3.5 inches of rain fall on the heap and that no losses to evaporation occur. The 100-year, 24-hour, storm event for this area is 2.0 inches; thus, it is possible that such conditions may preclude leachate generation. Sixty of the 79 heap leach operations in the United States are located in semiarid regions of Nevada, where capping to reduce infiltration may not be necessary. Some operations, however, are located in areas that receive considerable rainfall (South Carolina) and precipitation in the form of snowfall (Montana). At these locations, capping at closure may be a control option.

Heaps are constructed with steep (1:1) side slopes, which are usually dictated by the natural angle of repose of the ore. Heaps are stacked as steeply as possible to maximize the use of pad area. Such steep slopes cannot be capped. The slopes would have to be reduced to at least 3:1 for capping to be applicable. The cost of slope modification would vary with the original size and height of the heap. For example, regrading a 1-acre heap having 1:1 slopes and a height of 15 ft would require movement of 1700 yd^3 of material at a cost of about $2500. After slope modification, the surface area of the heap would be 1.4 acres. Application of a cap consisting of 3 feet of earth would require 6800 yd^3 of cap material. Assuming a suitable source could be found near the site, the cap could cost about $36,000. A large heap (e.g., one covering 50 acres and having a height of 100 ft) would require the regrading of 550,000 yd^3 of material. The modified heap would require capping to be placed over 67 acres at a total cost of $1.8 million.

Although capping can reduce the potential for leachate formation by limiting infiltration, it also reduces the rate of natural degradation of cyanide left in the heap leach residue. Because the cap would limit natural aeration of the heap, it would reduce volatilization of any free cyanides present.

POST-CLOSURE MONITORING AND MAINTENANCE

After the closure of heap leach operations, the leach residue is the only potential source of cyanide contamination, assuming that the process solution ponds have been removed as required. Leach sites in typically arid climates have less potential for long-term impacts than leach operations where significant precipitation or surface water flows are present. Monitoring requirements normally also would be less in the dry areas. Monitoring of ground-water wells installed at the time of closure would be continued through the post-closure period. The typical RCRA post-closure monitoring period extends over a period of 30 years. As an alternative, the monitoring of wells used during the active life of the operation can continue through the post-closure period if such wells are available. In addition to the monitoring of ground water, maintenance of the monitoring system, and any other controls, such as caps or access control fencing, also may be required. The annual cost of maintaining such systems is usually estimated to be 1 to 5 percent of their capital cost. The cost of monitoring ground water varies with the number of wells, the required samples, the number of duplicates, analytical parameters, etc. The cost of this monitoring will vary widely and depends primarily on the number of wells. For example, the cost to monitor a relatively small site having eight wells around the heap would be about $6400/yr for analytical services plus the costs of reporting and recordkeeping.

SECTION 6

SUMMARY OF FINDINGS

The information gathered and evaluations made during this study of gold/silver heap leach operations are summarized in the following four subsections paralleling the organization of this report.

GENERAL CHARACTERISTICS

Although other industry segments have experienced closures and production cutbacks, the practice of gold heap leaching continues to increase dramatically. The low production cost (e.g., $200/ounce), short startup time, and relative simplicity of heap leaching have made it the method of choice for recovering low-grade deposits. Also, because the production of gold as a byproduct of copper mining has declined as a result of cutbacks in that industry, demand must be met by other sources. In 1984, heap leaching accounted for more than 30 percent of total gold production, and the surge of activity in this industry segment is expected to continue.

Of the 66 currently active gold heap leach operations that were identified, 47 are located in Nevada. In fact, Nevada accounts for about half of the total gold produced in the United States. Heap leach operations are scattered throughout this sparsely populated, typically arid State. With the exception of one operation in South Carolina, the remaining operations are also located in Western States. Exploration activity, however, is occurring throughout the country.

DESIGN AND OPERATION

The basic design and the operational layout of heap leach projects are similar at all facilities; however, site-specific conditions (especially ore mineralogy) control specific practices and applications. An alkaline cyanide solution is used universally as the lixiviant in heap leaching; however, specific ore treatment, leaching time, reagent use, flow rates, heap construction, pad specifications, liner materials, and other site-specific parameters depend on the ore mineralogy, climate, topography, hydrology, and hydrogeology at each site. Heap leach operations are relatively small, discrete operations compared with other mining operations.

The use of liners to prevent loss of process solutions is standard industry practice. Leach pads are constructed of asphalt, clay, or synthetic materials. The two process solution ponds at each site are lined with synthetic material (e.g., HDPE or Hypalon). Some operations have incorporated redundancies and overdesigns into their liner systems. These include such items as leak detection (e.g., French drains) in pad construction and ponds constructed with double liners and leachate detection systems. The degree to which these features are incorporated depends on the regulator (e.g., California requires double liners) and the potential for impact (e.g., many operations in Nevada are very remote, miles away from any surface water and situated over deep ground water, whereas operations in other states may be located near surface and ground waters where advanced systems would be appropriate).

TOXICITY AND MOBILITY

An extensive data base is available on the toxicity of various cyanides and cyanates; however, very little information is available on the quantity and speciation of cyanides and cyanates present in heap leach residue. Therefore, it is difficult to assess the potential for environmental impact that may be caused by leach residue.

The toxicity of cyanides varies from the acutely toxic free cyanide (HCN) to some nontoxic iron and cobalt metallocyanide complexes. Thiocyanate has relatively low toxicity. The types of cyanides and cyanates present in leach residue and process solution depend on the ore mineralogy. Process solutions contain significant quantities of free cyanide.

ALTERNATIVE MANAGEMENT PRACTICES

French drains may be incorporated into the design and construction of leach pads and could provide early warnings of process solution leakage through the pad. This kind of system has been used at a few active operations. Incorporation of a French drain system roughly doubled the cost of an example clay pad. The need for and applicability of such a system must be determined on a site-by-site basis.

Double liners (synthetic or synthetic over compacted clay) with leachate detection/collection may be incorporated into the design and construction of the two process solution ponds used at each site. Double-liner systems represent a proven technology that could be used at gold heap leach operations. A synthetic double-liner system costs at least 2 times the amount of a single-liner system, which is the industry standard. Although the solution in the pond is not a waste, leakage or seepage is, and double liners would add another level of protection against failure of the impoundment. In some settings, full double liner systems might be an unnecessary design redundancy (e.g., locations over thick clay zones and/or away from ground water).

Currently, no alternative lixiviants are available to replace cyanide. Research is continuing on alternatives (e.g., thiourea); however, their application has not been demonstrated on a commercial scale. Although the use of other reagents may remove real or perceived problems with cyanide, they could pose other environmental concerns. Thiourea, for example, requires a very acidic (pH 1) process solution.

Implementation of increased monitoring of ground water or the vadose (unsaturated) zone beneath leach pads and solution ponds is a possibility. Heap leach operations entail three potential sources of contamination: the leach pad and two solution ponds. After closure, only one source, the heap leach residue, remains. By mining industry standards, these operations are small and discrete and do not pose the problems typically encountered in monitoring very large mining operations. The extent of monitoring at active operations varies depending on regulatory requirements currently in place, hydrogeological settings, and the extent of the design of containment systems. Installation of a ground-water monitoring system at a small example site having a 5-acre leach pad and two process ponds could be expected to cost between $12,500 and $195,000 plus consultant fees of between $6,000 and $50,000. Depth to groundwater is the major variable. These estimates assume 10 to 13 wells with depths of 25 to 300 ft. Lysimeters are less desirable because of the difficulty in obtaining samples and lower reliability.

Current industry practice includes rinsing of heaps with fresh water at the completion of the leach cycle or during closure. Limits are set by the State or other regulators on the amount of cyanide (e.g., less than 0.2 mg/liter) that can be present in rinse water and the pH (e.g., pH 8.5) of the rinse water leaving the heap. At least a few sites have incorporated alkaline chlorination during the rinse process to enhance degradation of cyanides. An example alkaline chlorination system capable of treating 300,000 tons of leach residue annually would cost about $280,000 for installation. The lack of data on the effectiveness on water or chlorine rinses or on the cyanide content of leach residue makes it impossible to assess the need for and benefits of additional treatment.

A cap could be added to the heap at closure to prohibit leachate formation. Placement of a cap that would limit infiltration of precipitation into the heap would require recontouring to lessen the slope of the sides. Capping may not be applicable at many sites because of the typically arid nature of the area, particularly those in Nevada. At sites in areas that receive significant precipitation, however, capping may provide environmental benefits if potentially mobile cyanides are present in the residue. Capping costs are in the range of $28,000 per acre, assuming a 1-meter-thick earthen cap and the availability of suitable cap material on site. Recontouring heaps to a 3:1 slope could cost as little as $2,500 for a small heap (1 acre, 15 ft high) to $800,000 for a large heap (50 acres, 100 ft high). Costs of placing the earthen cap on these two example heaps would be about $36,000 and $1.8 million, respectively.

Post-closure monitoring can be implemented to determine if potentially mobile forms of cyanide in heap leach residue are causing contamination of ground water, the unsaturated soil zone, or surface water, if present. In the post-closure period, only the leach residue remains as a potential source of contamination. The two process solution ponds typically must be removed during closure as part of the permit requirements. A ground-water monitoring system could be maintained during the post-closure period to ascertain if cyanide is migrating from the leach residue. Annual analytical costs could be about $6,400 for a small (8 well) system. Post-closure monitoring typically is carried out over a 30-year period.

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APPENDIX A

TRIP REPORTS

REVISED TRIP REPORT
PINSON MINING COMPANY

EPA Contract No. 68-02-3995
PN 3650-24

Prepared by
PEI Associates, Inc.

(Draft Trip Report revised per comments received from John Pekrul July 7, 1986)

The Pinson Mining Company operations (Pinson and Preble Mines) near Winnemucca, NV were visited on May 19, 1986. The objectives of the visit and tour were to gain a familiarity with the Pinson operation and to discuss the current precious metals heap leach project being conducted by PEI for the EPA. The following personnel participated in the meetings and tour:

Jack Hubbard - U.S. EPA Project Officer
Robert Hoye - PEI Project Manager
Dan Harper - Pinson General Manager
Bruce Thorndycraft - Pinson Mill Superintendent
Keith Belingheri - Pinson Chief Mine Engineer
John Pekrul - Pinson Chemist
Norm Greenwald - Newmont Gold Co. representing Nevada Mining Association

An initial meeting was held to discuss the EPA's mine waste program in general and the current project in detail. Pinson personnel gave an overview discussion of the operations. Pinson personnel then gave detailed discussions of the various operations during a site tour. A follow-up meeting was held after the tour to further discuss the operations. Pinson provided PEI with two engineering diagrams of the Pinson heaps. Additionally, photographs of the facilities were taken by PEI and EPA during the tour. Discussion of the Pinson and Preble operations are presented separately in this trip report. This trip report includes some information included in a pamphlet on the Pinson operations provided by Pinson personnel.

Pinson Mine

General - The Pinson heap leach operation is relatively new having started year round production in 1982. The Pinson open pit mine feeds both a mill, which is the major source of gold recovery, and the heaps. The heap leach facility is situated about 1.5 miles from the pit. Currently about 2 million st of material are on the heaps. The heaps currently cover about 40 acres. The pads are constructed of compacted clays and are permanent (single-use) facilities. Run-of-mine material grading 0.02 to 0.03 oz. gold per st is leached with an alkaline sodium cyanide solution. Pregnant solution is collected in lined trenches, flows to a lined collection pond and then to the carbon adsorption plant. Barren solution is returned to the heaps. The water table is reported to be about 150 ft below ground level.

Profitability of heap leached gold is enhanced by the necessity to remove this material from the mine in order to mine mill-run grade ore. Therefore, the only additional cost incurred is the haulage from the waste dump where it would have gone, to the heaps, and the heap construction and solution management costs. The ability to leach run-of-mine ore is also a large contributor to the endeavor. Pinson is able to leach material grading 0.01 to 0.04 oz gold/st that would otherwise have been dumped in the waste rock piles.

Pad Construction - The heap pads are constructed on a naturally sloping (3 to 6 %) valley floor. Topsoil is first removed and stockpiled. The sub-base of native soils then is compacted. Two 6-inch lifts of local clays (alluvial lake bed material) are then placed and compacted using a sheepsfoot roller with a vibratory steel drum. The permeability of the clay liner is determined through compaction tests and the use of a nuclear densiometer. The sub-base is compacted to achieve permeabilities between 10^{-5} and 10^{-6} cm/sec. The pad liner is compacted to acheive permeabilities between 10^{-6} and 10^{-7} cm/sec.

French drains constructed of 2-inch diameter schedule 40 PVC pipe are placed under the pads to monitor for leakage through the pad. The pads slope to two sides, the French drains are located along the downstream sides as shown in Figure 1. These drains are connected to sumps which are monitored to determine if any individual pad is leaking. To-date one of the twenty pads has shown some weeping. Any solution found in the drain system is returned to the solution handling system.

Collection ditches are constructed along the two down-slope sides of the pad and are lined with 37 mil reinforced hypalon that is keyed into the clay pad. Four inch diameter perforated PVC pipe and clean gravel are placed in these lined ditches.

Pads are nominally 300 ft by 380 ft diamond shaped areas which take advantage of the natural ground contours. Initally it was planned that over the life of the mine, approximately 60 pads would be constructed, each capable of holding 90,000 st at 20 ft of heap height. Current operations, however, involve stacking second and possibly third lifts on top of leached heaps. The individual heaps butt against each other, giving the appearance of a single heap. Leaching and stacking are done in a manner that allows four individual heaps to be leached at the same time without intermingling pregnant sloutions prior to their introduction to the pregnant solution pond. The flow rate and chemical characteristics of these individual solutions are monitored.

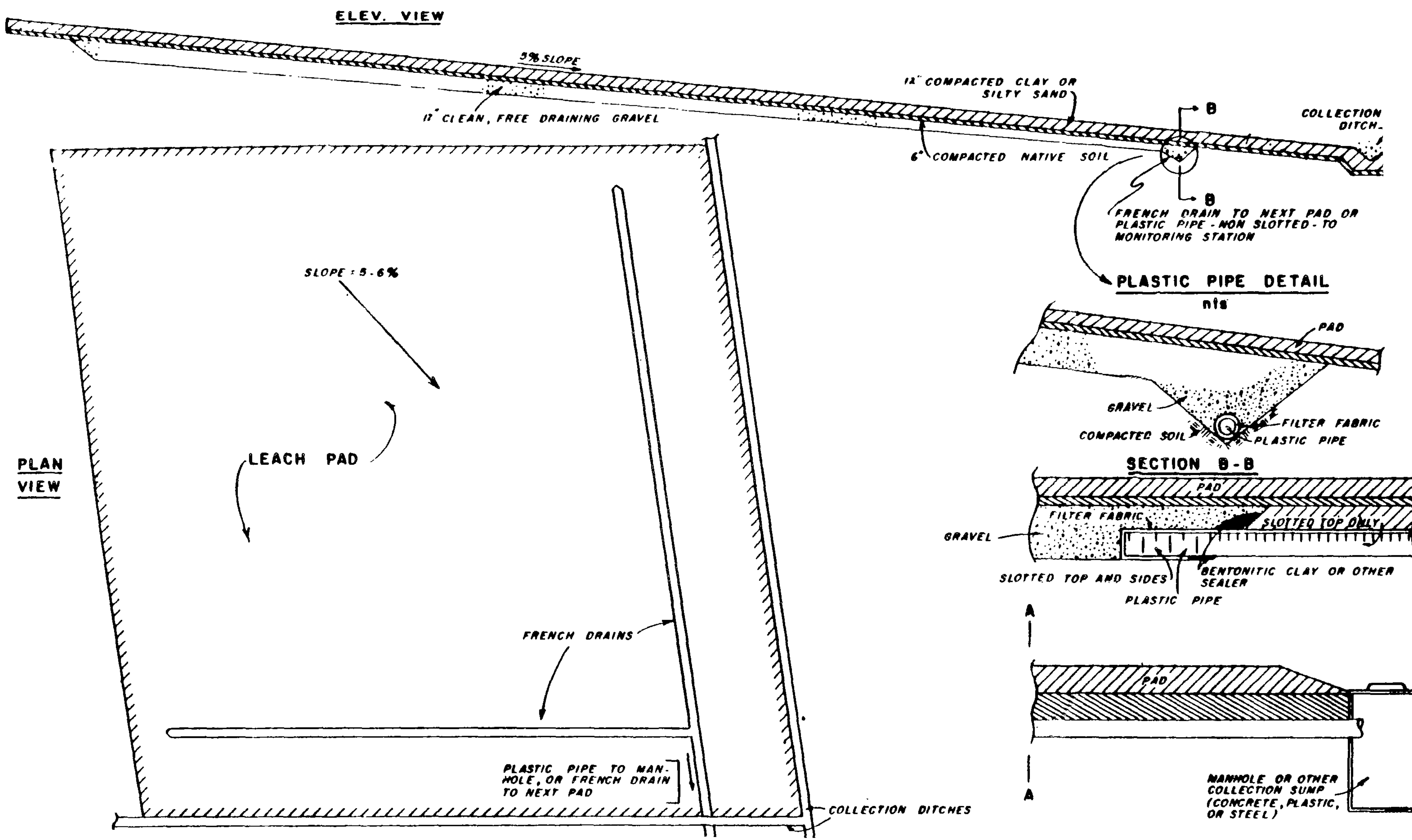
Permanent asphalt pads were considered, but were not used because it was desirable to be able to releach the ore over extended periods of time for additional gold recovery, and because the cost of moving the ore twice was avoided.

Heap Construction - After a pad has been constructed, a layer of 8 to 12 inches of gravel is placed over the pad to protect it from damage by earth moving equipment , to provide a permeable drainage blanket, and to protect the clay from erosion. The run-of-mine low grade ore is placed to a height of about 15 ft using a front loader. Once a heap has been leached a second 15 ft lift of leach material is placed on top of it and leached.

Leaching - A total of 2 to 3 leach cycles are applied to an individual heap, over a period lasting from 9 months to a year. Initially the heap is leached for 45 to 90 days. During this time 55 to 60 % of the gold values are obtained. The second leach of a heap is usually conducted after the heap has gone through a winter season. This allows oxidation and weathering of the rock to occur. Additional gold, 2 to 5 % of the total, is recovered during this leach. Depending on production schedules, a third leach cycle may be used. Because of their ability to re-leach the heaps and recover more gold, Pinson views the heaps as a resource and not as waste on the pad.

The volume of solution applied to the heaps is measured using both magnetic and mechnical flow meters. The volume of solution collected from each heap is measured using flumes. Solutions from each heap are monitored separately to allow more precise metalurgical control of the operation.

About 250,000 gal of leach solution are required to saturate an individual heap. Initial breakthrough of solution is achieved about 18 hours after solution application is begun and a steady state flow is achieved after about 72 hours. These parameters do not vary significantly when a second leach cycle is conducted. The initial moisture content of



ELEV. VIEW
5% SLOPE
12" COMPACTED CLAY OR SILTY SAND
12" CLEAN, FREE DRAINING GRAVEL
6" COMPACTED NATIVE SOIL
COLLECTION DITCH
B
B
FRENCH DRAIN TO NEXT PAD OR PLASTIC PIPE - NON SLOTTED - TO MONITORING STATION
PLASTIC PIPE DETAIL
nts
PAD
GRAVEL
FILTER FABRIC
COMPACTED SOIL
PLASTIC PIPE
SECTION B-B
A
A
PAD
FILTER FABRIC
SLOTTED TOP ONLY
GRAVEL
BENTONITIC CLAY OR OTHER SEALER
SLOTTED TOP AND SIDES
PLASTIC PIPE
A
A
PAD
MANHOLE OR OTHER COLLECTION SUMP (CONCRETE, PLASTIC, OR STEEL)
PLAN VIEW
SLOPE = 5-6%
LEACH PAD
FRENCH DRAINS
PLASTIC PIPE TO MANHOLE, OR FRENCH DRAIN TO NEXT PAD
COLLECTION DITCHES

the run-of-mine ore is about 5 percent. The moisture content of ore under steady state leaching conditions is 14 to 15 percent.

The barren solution applied to the heaps contains 80 to 100 ppm cyanide and has a pH of 10.3 to 10.5. The solution is delivered through 8-inch HDPE pipe, then distributed by 3-inch pipe and wobbler and rainbird sprinklers on 40-foot centers.

The pregnant solution contains 8 to 10 ppm cyanide and has a pH of 8.0 to 9.5. Reagent usage amounts to 0.3 pounds of NaCN per ton of ore and is very consistent in practice.

Solution Handling - Solution is collected in the low corner of each pad by a "manhole" system consisting of three 12-inch diameter steel pipes with slotted caps installed vertically. Pregnant solution from each of the four heaps being leached flows to a common pregnant solution pond via 6- and 8-inch HDPE piping. This pond has a volume of 2.2 million gal. The pond is lined with 40 mil HDPE (heat welded seams) which was placed over 8-inches of compacted clay. A French drain monitoring system, similar to that described for the leach pads, is located beneath the liner. Pregnant solution is pumped to the carbon adsorption plant and barren solution is pumped to a pond situated adjacent to the pregnant pond. The barren solution pond has the same construction details as the pregnant solution pond and has a volume of 1.1 million gallons. NaCN and caustic are added to the flow into the barren pond. Barren solution is then pumped to the heaps.

A clay lined pond with 3 million gallons of capacity provides overflow protection for the pregnant and barren solution ponds.

Residue Disposal - Pinson uses dedicated single-use pads, leached material is spoiled in-place. Pinson re-leaches its heaps when additional gold recovery can be obtained and when it benifits the water balance of the operation.

Preble Mine

General - The Preble mine is a satellite operation of the Pinson mine. Mining and heap leach operations began at this site in 1984. Most of the ore mined will be leached on-site, however, some will be hauled to the Pinson mill for processing. The heap leach process includes crushing and agglomerating prior to leaching. Gold from the pregnant solution is adsorbed onto carbon which is hauled to the Pinson mill for stripping. Other aspects are similar to the Pinson operations.

Pad Construction - Pad construction at Preble is the same as at Pinson with two exceptions: permeability of the Preble clay pads is 10^{-7} to 10^{-8}; and two pads at Preble are lined with 30-mil PVC. Plastic liners were used because these pads were constructed in winter weather. Clay cannot be properly worked in cold weather.

Heap Construction - Run-of-mine ore is crushed and agglomerated with 8 pounds of Portland No. 2 cement per ton of ore. Fresh water is also added during agglomeration. Agglomerated ore is stacked on the heaps by a front loader to a height of about 17 ft. Currently, about 400,000 st of ore are on the the Preble heaps.

Leaching - The leaching operation is similar to that at Pinson except that it is conducted only in warm weather. Like Pinson the barren spray at Preble contains 80 to 100 ppm cyanide, however, the pregnant solution contains 50 ppm cyanide and has a pH of 10.3 to11.0 (the alkalinity of the cement keeps the pH up). The barren spray has a pH of 10.3 to 10.5. At Preble, 0.2 pounds of NaCN are consumed per ton of ore leached.

Solution Handling - Pregnant solution is collected in ditches lined with 37-mil reinforced hypalon. This solution flows to a lined pregnant pond then to carbon adsorption columns then to a barren pond. The pregnant and barren ponds are lined and monitored for leakage with the same specifications presented for the Pinson ponds.

Residue Disposal - Preble leached ore is spoiled-in-place on the dedicated single-use pads. This provides for long term management and allows re-leaching if appropriate.

REVISED TRIP REPORT
NEWMONT GOLD COMPANY
(FORMERLY CARLIN GOLD COMPANY)

EPA Contract No. 68-02-3995
PN 3650-24

Prepared by
PEI Associates, Inc.

(Draft Trip Report was revisied per verbal comments received from Norm Greenwald on July 21, 1986.)

Carlin Gold Company operations (Carlin-2/Gold Quarry and Maggie Creek operations) near Carlin, NV were visited on May 20, 1986 . The objectives of the visit and tour were to gain a familiarity with the Carlin operations and to discuss the current precious metals heap leach project being conducted by PEI for the EPA. The following personnel participated in the meetings and tour:

Jack Hubbard	-	U.S. EPA Project Officer
Robert Hoye	-	PEI Project Manager
Norm Greenwald	-	Newmont Services Ltd. and Nevada Mining Association
Walt Lawrence	-	Newmont Gold Company, Manager of Mill Operations

An initial meeting was held to discuss the EPA's mine waste program in general and the current project in detail. Mr. Lawrence gave an overview discussion of the operations. Mr. Lawrence and Mr. Greenwald then gave detailed discussions of the various operations during a tour of the site. Photographs of the facilities were taken by PEI and EPA during the tour. Discussion of the Carlin-2/Gold Quarry and Maggie Creek operations are presented separately in this trip report.

Carlin-2/Gold Quarry Operation

General - This is a new operation, construction of the heap leach operation was started in April 1985 and leaching began in March of 1986. Both heap leaching and conventional cyanidation milling are conducted on-site along with open-pit mining. Run-of-mine low grade ore is leached on dedicated single-use pads with HDPE liners. Leaching is planned to be conducted in three phases. Construction of the first phase, consisting of two 50-acre pads, is just being completed. Subsequent phases will involve additional pads constructed near the mine site.

Pad Construction - Phase 1 leaching operations consist of two 50-acre heaps. The first of these heaps has been constructed and has been leached since March 1986. The pad of the second heap is currently under construction.

The first step of pad construction was to clear and grubb the area. The sub-base was then compacted. Internal dikes are constructed in the base to segregate flow of leach liquor. An 80-mil HDPE liner was then placed over the entire pad including the collection ditches. Seams of the liner material were heat welded, the integrity of the seams was verified through a quality assurance testing procedure. A 2-ft layer of graded gravel was placed over the plastic liner. The gravel serves to protect the liner during heap construction and to provide a high permeability blanket over the liner to prevent build-up of hydraulic head during leaching.

Two monitor wells have been installed and are monitored. The wells are located immediately downgradient of the leaching operation. They intersect groundwater at a depth of about 70 ft.

Heap Construction - Run-of-mine low grade ore is dumped by haul trucks onto the liner to form a single 50-ft high lift. Detailed geotechnical investigations were conducted of the foundation and the heaps themselves to ensure stability. The material is spread by dozer then ripped and cross-ripped using a Cat D9L with a 6-ft ripper. Pebble lime is added to the ore in the haul trucks at a rate of 3 lb/st of ore to ensure that the alkalinity is maintained at a pH of 10.0 to 10.5.

The ultimate height of the heap currently is under evaluation, it may go as high as 200 ft. Current production sends 300,000 st of ore to the heaps each month, at full operation 4.5 million st will be placed on the heaps annually. There now are about 1 million st of ore on the pads.

Surface water is diverted around the area of the heaps chiefly by the tailings pond and dam situated upgrade of the leaching operation.

Leaching - Barren solution is sprayed over the heap using wobbler sprinklers with individual pressure regulators. The total flow of the pregnant solution is about 4000 gal/min. If the ultimate height of the heap reaches 200 ft then the pads will be in production for about 10 years. Figures on reagent usage were not immediately available. Likewise information on water balance (volume of barren solution and the moisture content at steady state leaching) were not available. The initial moisture content of the ore is 6 %.

Solution Handling - Pregnant solution is collected in ditches along the two down-slope sides of the heap. The pH of both pregnant and barren solutions is 11.4. The ditch is lined with 80-mil HDPE and is actually a continuation of the pad. About 4000 gal/min of pregnant solution flows to the pregnant solution pond. This pond has a hypalon liner. An emergency overflow pond is located immediately downgradient of the pregnant pond. This pond is lined with natural clay. The heap leaching operation is designed as a zero discharge facility.

Residue Disposal - The heaps at the Carlin-2/Gold Quarry operation are constructed on dedicated single-use pads. The leached material will be spoiled-in-place on the plastic liner at completion of leaching and following a rinse with fresh water.

Maggie Creek Operations

General - The Maggie Creek operation is located adjacent to the Carlin-2/Gold Quarry operation. The Maggie Creek mine pit will eventually be engulfed by the Carlin-2 pit. Unlike Carlin-2 the ore is crushed, agglomerated and leached on restackable asphalt pads at Maggie Creek. The ore grade is 0.03 oz gold/st.

Pad Construction - A single, restackable asphalt pad is used in the heap leach operations at Maggie Creek. The pad is nominally 850 by 260 ft. The pad slopes 3 percent over the short dimension and 2 percent over the long side. The pad was constructed by excavating the sub-base then placing a 2-ft thick engineered clay fill base. Next a 5-inch layer of asphalt was placed over the pad. A 2-inch thick rubberized asphalt membrane (sealcoat mixed with ground rubber) was placed over the asphalt. Another 2-inch layer of asphalt was placed over the rubberized membrane. Finally, a top coating of seal coat was applied. The pad liner extends to line the pregnant solution collection launders.

Carlin personnel indicated that, in retrospect, they would probably use a dedicated single-use pad instead of the restackable pad in current use.

Heap Construction - Run-of-mine ore is crushed to a minus 1.5 inch size then agglomerated with 5 to 6 pounds of portland cement per ton of ore. No cyanide is added during the agglomeration process. The agglomerated ore is loaded onto the pads by front-end loader to a height of 16 ft. The pad is divided into 5 seperate heaps. Each heap contains 16,000 to 18,000 st of ore. About 900,000 st of ore are placed on the pads annually.

Observation wells have been installed at the immediate downgradient corners of the pads to detect if seepage through the pad is occuring.

Leaching Cycle - A complete leach cycle takes about 25 days for each heap. This cycle consists of 2 to 3 days to load the heap, 15 to 18 days of actual leaching, 1 day to drain, 2 to 3 days for a fresh water rinse, and 1 day to remove (spoil) the leached material and place it in the disposal area (Carlin-2 tailings pond). During this leaching cycle 65 to 70 percent of the gold is recovered. Studies conducted by Carlin have indicated that longer leaching cycles do not seem to increase recovery. Leaching is carried out essentially year round (solution heating is used in the winter).

Reagent usage is 0.3 lb cyanide /st of ore leached.

At any given time 2 or 3 heaps will be leaching, 1 will be rinsing, and 1 will be under construction. Barren solution is sprayed over the heaps using wobbler sprinklers.

Solution Handling - Approximately 600 gal/min of pregnant solution is collected from the heaps. This solution flows through launders along the downstream sides of the pad to the pregnant solution pond. The launders are of the same construction as the pad and are a continuation of it. The pregnant solution pond is lined with 36-mil scrim reinforced hypalon. This solution is pumped to carbon adsorption columns for gold recovery. Barren solution is returned to a lined pond adjacent to the pregnant pond and is then pumped to the heaps.

Residue Disposal - Spoil from the heap leaching operation is removed using a front end loader and placed in haul trucks. The spoil is disposed of by end dumping on a spoil pile. The spoil pile is located in an area that will become part of the Carlin-2/Gold Quarry tailings impoundment.

REVISED TRIP REPORT
ROUND MOUNTAIN GOLD CORPORATION

EPA Contract No. 68-02-3995
PN 3650-24

Prepared by
PEI Associates, Inc.

(Draft Trip Report revised per comments received from Donald L. Simpson on July 31,1986.)

The Round Mountain Gold Corporation's Smoky Valley Common Operation near Round Mountain, NV was visited on May 21, 1986. The objectives of the visit and tour were to gain a familiarity with the Smoky Valley operation and to discuss the current precious metals heap leach project being conducted by PEI for the EPA. The following personnel participated in the meeting and tour:

Jack Hubbard - U.S. EPA Project Officer
Robert Hoye - PEI Project Manager
Otto Walls - Round Mountain Gold Mill Manager
Norm Greenwald - representing Nevada Mining Association

An initial meeting was held to discuss the EPA's mine waste program in general and the current project in detail. Mr. Walls gave an overview discussion of the operations. Mr. Walls gave detailed discussions of the various operations during a site tour. Photographs of the facilities were taken by PEI and EPA.

General - Smoky Valley is the world's largest gold heap leaching operation. Ore from the open pit mine is crushed and placed on restackable asphalt pads. After leaching the ore is hauled to an adjacent spoil pile. Field evaluations of a single-use pad with an 80-mil HDPE liner are underway. These evaluations will determine the design of future leaching facilities for Type 2 ore. Type 1 ore, that which has been mined to-date, has been processed as described below.

Pad Construction - The restackable pad is constructed of a 7 inch thick asphalt layer which has a rebberized asphalt membrane 2.5 inches from the bottom of the pad. A 2 foot thick layer of graded (1 inch) ore is placed over the asphalt to protect it and to provide drainage for the heap. The larger of the two pads is nominally 2500 feet long by 280 feet wide. The smaller pad is 650 by 280 feet. The pads are sloped at about 4 percent to the collection ditch.

Heap Construction - Currently about 18,000 st of ore (0.03 to 0.04 oz./st) are placed on the pads each day. Ore is crushed in an open-circuit, three-section crushing plant. Lime is added to the crushed ore stream, at 3 lb/st , before the conveyor discharges into an automated truck loading bin. The crushed ore is dumped on top of the coarser layer and pushed up to a height of 35 ft.

The pads are continuous but divided into 30 areas for solution distribution. The heap is 250 ft. wide at the base and 200 ft. wide on top. Current operations put up one half of a solution distribution area per day. Total leach pad capacity is 1.2 million st.

Leaching Cycle - Each individual heap is leached for 50 to 55 days, drained for one day, then rinsed with fresh water for 3 to 4 days. Sodium cyanide solution is added to the leach solution to maintain a concentration of1 lb/st of solution; the stripped and barren solution that is recycled contains a residual cyanide concentration of about 0.7 lb/st of solution, cyanide usage is about 0.1 lb/st of ore.

Leach solution is heated during the winter so that leaching can be continous.

Leach solution is distributed over each individual heap by 30 wobbler sprinklers placed in staggered arrangement. Each wobbler sprays at 4 to 5 gal/min. A total of about 2,700 gal/min are sprinkled on the entire leach pile and about 2,300 gal/min flow out of the bottom of the pile. The remaining 400 gal/min is absorbed by the ore particles or is lost to evaporation.

Solution Handling - About 2,300 gal/min of pregnant solution containing 0.04 oz gold/ton flows out of the heaps and to the pregnant solution sump. Unlike other sites visited, large pregnant solution and barren solution ponds are not present at this site. Instead, Smoky Valley uses a system of sumps that allow control of these solutions. One large containment pond is in place to back-up three sumps.

Residue Disposal - After each heap is leached and rinsed it is excavated by a front-end loader and hauled by trucks to the spoil disposal area. As the loading operation moves from one end of the pad to the other, a 75- to 100 ft.-wide slot is cut through the barren pile. One side of the slot is being loaded, while a new heap is being built at the opposite side of the slot. It takes 60 days for this moving slot to move through the entire leach pile.

The spoil is end dumped over a face that is about 150 ft high. The spoil spreads over this face and quickly dries. About 30 million st (an estimate by site personnel) of spoil have been placed on this pile.

REVISED TRIP REPORT
NERCO METAL'S CANDELARIA MINE

EPA Contract No. 68-02-3995
PN 3650-24

Prepared by
PEI Associates, Inc.

(Draft Trip Report revised per comments received from Michael Minette July 18, 1986)

NERCO Metal's Candelaria Mine, located 135 miles southeast of Reno, NV was visited on May 22, 1986. The objectives of the visit and tour were to gain a familiarity with the Candelaria heap leach operation and to discuss the current precious metals heap leach project being conducted by PEI for the EPA. The following personnel participated in the meeting and tour:

Jack Hubbard	-	U.S. EPA Project Officer
Robert Hoye	-	PEI Project Manager
Mike Minette	-	Candelaria Permits and Planning Engineer
Pat James	-	Candelaria Safety Engineer
O. W. Lively	-	NERCO Minerals, Manager Environmental and Safety Affairs
Norm Greenwald	-	Newmont Services, Ltd. representing Nevada Mining Association

An initial meeting was held to discuss the EPA's mine waste program in general and the current project in detail. Mr. Minette gave an overview discussion of the Candelaria operations. Mr. Minette then gave detailed discussions of the various operations during a site tour. Photographs of the facilities were taken by PEI and EPA during the tour. A pamphlet titled "Candelaria Mine" was provided by site personnel and provided supplemental information.

General - The Candelaria mine is the largest open-pit silver mine in the country. The mine was opened in 1980 by Occidental Minerals and closed in 1982 due to depressed silver prices. NERCO Minerals acquired Occidental and reopened the mine in February of 1983. All ore is crushed, agglomerated and treated by heap leaching with cyanide. Dedicated single-use clay or HDPE lined pads are used, with multiple lifts of ore placed and leached. Ultimate heap height is 120 ft. Leach residue will be spoiled in-place at closure.

Mining operations currently handle 57,000 st of material daily, 10,000 st of which is ore. Over 2 million oz of silver will be produced this year. The ore grade cutoff is 0.5 oz/st. The silver occurs in oxide ores, sulfides are less than 0.1 percent. Site personnel point out that oxide ores do not have the acid formation potential of sulfide ores. Additionally the Candelaria ore does not have any carbonaceous material associated with it. (Carbonaceous material is a cyanicide and increases reagent usage.)

The site receives about 8 inches of annual rainfall, of which about 2.5 inches is snow. Eleven wells have been installed in the area of the pads. Each of these wells are plumbed quarterly and are dry. The area of the pads has been drilled to a depth of 500 ft without hitting water. There is no surface water for an 8 mile radius. There are no residences within 5 miles.

Pad Construction - The Candelaria heap leach system uses 7 adjacent pads. Each pad is 1300 to 1500 ft long and 300 ft wide. The combined pad area is 2100 ft wide by 1300 ft long on one side and 1500 ft long on the other. Plans include adding 2 more pads to this system in the near future, ultimately a total of 12 pads could be constructed with the available area. Five and a half of the 7 existing pads are constructed of clay, the other one and a half pads are newer and are lined with HDPE.

The clay lined pads were constructed by first clearing and grubbing the area. The sub-base was then brought up to optimum moisture content and compacted to 95%. Clay imported from a borrow pit located 5 miles away was placed in three 6-inch lifts. The clay liner was compacted to 99% of its dry density to achieve a permeability of 10^{-7} cm/sec. The clay liners are keyed to a hypalon lined collection ditch on the downstream side. The pads are tilted at a slope of 1.5 to 5 % towards this ditch.

The HDPE lined pads were constructed by first clearing and grubbing the area. A 4-inch layer of clay and soils compacted to 95% dry density was then placed over the area. An 80-mil HDPE liner was then put down. This pad liner was joined to a 100-mil HDPE collection ditch liner.

Candelaria conducted comprehensive geotechnical studies on several different pad construction materials. For example, the use of bentonite and montmorillonite as additives to clay liners was explored. In addition, they have evaluated the effects of UV radiation, temperature variations, slope, and chemical compatability during the pad selection process. It has been determined that the existing pads can support heap heights of 140 ft. and sub-base slopes of 6 % without damage. Pad No. 1 is currently at a height of 110 ft. A new pad can be put into service in about 3 months.

Heap Construction - Run-of-mine ore is crushed to minus one inch in two stages. The ore is then agglomerated by tumbling and wetting with NaCN solution. The agglomerated ore is hauled by truck to the leach pads.

Heaps are constructed in 20 ft lifts. Ore is piled to a depth of 25 ft, the top 5 ft are pushed off and the heap is ripped with an 8 ft ripper on a Cat D9H. The top material is pushed off and the heap ripped to increase the heaps permeability. The 20 ft lifts are added to the heaps in a continuous sequence. It takes about 6 months for a lift to be added to a single pad. There are currently about 11 million st of ore in the heaps.

Leaching Cycle - Each 20 ft lift is leached for 45 to 60 days. Leaching is conducted year-round. In the winter, a trickle solution distribution system is buried in the heaps to a 4 ft depth. During other months, leach solution is sprayed over the heap at a rate of 0.005 gal/min per square foot using wobbler and rainbird sprinklers. Total flow to the heaps is 3000 gal/min.

Currently, 2.5 lb of caustic and 2.5 lb of cyanide are added to each ton of leach solution. The pH of this solution is 11.2, the pH of the pregnant solution is 10.5. The pregnant solution contains 0.45 oz silver per ton of solution.

The heaps will not be rinsed with fresh water until the time of closure.

Solution Handling - The Candelaria heaps are zero discharge facilities, the only outlet is to evaporation. Pregnant solution flows from the heaps to the HDPE lined collection ditch which feeds the pregnant solution pond. Two Hypalon lined ponds have capacities of 9.0 million gallons each. Currently, one of the ponds is used as a surge pond and the other is used for clean pregnant solution. These ponds are designed to contain any spillage in addition to runoff from a 100 year storm.

Pregnant solution is pumped from the pond to a surge tank, then to clarifiers which remove solids. The solution then goes to a vacuum tower where oxygen is removed. Zinc dust is added to precipitate the silver and gold which is recovered as a filter cake in filter presses. The filter cake is treated in a furnace and the dore bullion product is formed.

Barren solution flows to a lined pond located near the plant. Caustic and sodium cyanide are added to this solution before it is pumped back to the heaps as leaching solution. Process water from the clarifier backwash, plant washdown, et. is sent to a smaller lined evaporation pond located adjacent to the barren solution pond. Clean-out and any spillages from the agglomerator building are contained in a similar lined pond. When necessary solid residue from these ponds will be removed and placed on the heaps.

Surface water diversion ditches have been constructed upgradient of the heaps so that any storm water will not contact the heaps.

Candelaria has constructed some fresh water supplies for animals that live on or pass through the site. This keeps them from drinking the process waters. Additionally, the process water ponds are fenced. These are common practices at the heap leach facilities visited.

Residue Disposal - Heap leach pads in use at Candelaria are dedicated, single-use pads. The leached material will be spoiled in-place. At the time of closure, plans call for the heaps to be rinsed with fresh water. Exposed liner material (i.e. collection ditch liners) will be taken up and placed in the empty pregnant solution pond. The liner of that pond will then be folded over on itself and buried.

Alternatives to Cyanide - Candelaria personnel made the following points in addressing the feasibility of alternatives that they believe EPA may consider based on the Report to Congress:

Use of Thiourea	- Thiourea requires a very acidic environment. Candelaria estimates that for every ton of ore treated, 178 lb of H_2SO_4 and 8 lb of H_2NO_4 would be required. Current reagent usage is 2.5 lb of caustic and 2.5 lb of cyanide. Thiourea would cost an estimated $53 per oz of silver recovered, just for reagents (current price of silver is $5/oz)
Cyanide Destruction	- Would prohibit recycling of solutions. 1984 costs to operate with cyanide destruction (instead of recycling) would increase production costs by $4/oz of silver, it would require 15 million lb of added cyanide and would necessitate the use of a tailings pond.
Multiple-Use Pads	- Forcing the mine to remove ore from the single use pads would increase loading and haulage costs by $0.40/ton. Currently there are 11 million tons on pads thus multiple use pad would cost $2 million per year minimum.
Impermeable Cap	- To place an impermeable cap over the heaps at the end of operations would cost a minimum of $7.5 million for a 2 ft compacted clay layer.

TRIP REPORT
STATE OF NEVADA
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL PROTECTION

EPA Contract No. 68-02-3995
PN 3650-24

Prepared by
PEI Associates, Inc.

A meeting was held with personnel of Nevada's Division of Environmental Protection in Carson City, NV on May 23, 1986. The objectives of the meeting were to gain a familiarity with the state's approach to permitting and regulating heap leach facilities and to discuss the current project. The following personnel participated in the meeting:

Jack Hubbard - EPA Project Officer
Robert Hoye - PEI Project Manager
Harry Van Drielen - Nevada Environmental Management Specialist
Verne Rosse - Nevada Waste Management Program Director

An initial meeting was held to discuss the EPA's mine waste program in general and the current project in detail. Mr. Van Drielen gave an overview of his permitting activities and perspective on the heap leach industry. It was decided during the meeting that it would be possible and beneficial to make brief visits to two nearby heap leach operations. These two operations, Alhambra Mines and Nevex, are smaller operations than we had seen and are located in populated areas. These tours were then made with Mr. Van Drielen to get a better perspective of the industry.

The State takes a somewhat flexible approach to permitting and regulating heap leach operations. The type of pad and pond liner that will be used is agreed upon by the State and the heap operator. Similarly the operations and closure requirements are specified on a site-specific basis. Closure requirements for spoil are dictated by pH levels, the state requires operators to attain a pH of 8.5. Where cyanide has been liberated natural or background levels must be attained. There are 3 known sites in the state with cyanide contamination; 2 are inactive, historic facilities and the other is the Cortez operation.

One interesting point made by Mr. Van Drielen was that free cyanide occurs in detectable and measurable levels decades after release to the environment. Current literature indicates that free cyanides quickly decompose or are complexed to stable forms in the environment. He gave as an example a leak that occured at a cyanide loading station near Carlin, NV. A significant volume of cyanide solution was lost. This solution did not intersect groundwater but remained in the aerated zone in contact with earth rich in iron. The cyanide is being extracted by wells installed for that purpose, a process that has been going on for about 5 years. Free cyanide is still present in the solutions.

The biggest problem the State has with heap leach operations is with "sham" operators and with clandestine operations. "Sham" operators are those who develop a facility to the extent necessary to solicit investments and then abandon the facility potentially leaving cyanide contamination. Clandestine operations are typically small facilities in remote areas that operate without the state's knowledge or approval. These operations also often leave cyanide contaimination due to poor management practices and lack of controls.

Mr. Van Drielen indicated that the Maggie Creek and Round Mountain operations are the only multiple-use pads in the state.

The site visits made with Mr. Van Drielen are reported below:

Alhambra Mines

This heap leach operation is entering the closure phase. The facility leached old tailings from previous amalgamation milling processes. The tailings contain significant quantities of free mercury and some gold. Homes were built very near, and in some cases actually on, these tailings. Alhambra Mines excavated the tailings and placed them on two triple-lined pads. The pads are constructed of modified soil and two layers of PVC with leak detection between the PVC liners. Cyanide solution was sprayed over the heaps and mercury and gold were recovered from the pregnant solution.

Specific information on sizes and tonnages was not obtained, however, it appeared that the total area covered by the two heaps was less than 5 acres. The heaps are piled to a height of about 25 ft. Currently, the heaps are being flushed with water. Occupied houses are located within 100 yards of the facility. This operation has reduced a significant health risk by removing the free mecury from the site.

Nevex - The Nevex site is located near Carson City, NV on a hill- side above a populated area. A single heap is used to treat ore from an open pit mine located nearby. Photographs of the site were taken, but because of time constraints the site operator could not be interviewed. With the exception of the proximity to populated areas and its relatively small size, the Nevex operation appeared similar to others visited.